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TOTAL QUALITY MANAGEMENT (TQM), AN OVERVIEW

Anthony Coppola



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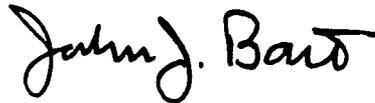
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INTRODUCTION

This report is essentially a slight modification of a tutorial paper prepared by the author for the the 1992 Annual Reliability and Maintainability Symposium. Since it provides a comprehensive overview of Total Quality Management (TQM), it was decided to publish it as a technical report so that it would be available to all interested parties, rather than just the symposium attendees. It will discuss the reasons TQM is a current growth industry, what it is, and how one implements it. It will then describe the basic analytical tools, statistical process control, some advanced analytical tools, tools used by process improvement teams to enhance their own operations, and action plans for making improvements. The final sections will discuss assessing quality efforts and measuring the quality of knowledge work.

WHY TQM?

"If we don't change directions soon, we are doomed to end up where we are headed," states an ancient Chinese adage. In 1970, 17 U.S. firms produced televisions; today there is only one. Most sets are imported because of higher quality and lower cost. In 1975, five of the six largest semiconductor manufacturers were U.S. companies; today six of the largest seven are Japanese. Are we heading where we want to go?

"If you always do what you always did, you will always get what you always got." Which is not good enough, as American auto makers found out when they lost market share to imports, again because of quality and cost.

"There ain't no more money," says George Butts, formerly of Chrysler Corp. He hastens to add that there is plenty of money around; there just is not any new source. So new profits must come from the same sources of income as present profits. However, since about 25% of manufacturing costs are absorbed by scrap, rework and waste, there is plenty of opportunity there.

Total Quality Management promises to improve quality and lower costs. It is therefore a means for survival, a way of increasing profits, and an insurer of jobs. It is also a way of enhancing job satisfaction by increasing a worker's pride in his product, and has an appeal to morality because through quality, the customer will be getting good value, the manufacturer enjoys a fair profit, and the worker will have a secure and satisfying job. Everyone wins.

WHAT IS TQM?

To clarify the concept of Total Quality Management, we will discuss the work of the best known quality "gurus," and examine some definitions used by various agencies. From these we will extract some common principles and some points of disagreement.

The most famous names in TQM are: Deming, Juran, Crosby, Fiegenbaum, Ishikawa, and Taguchi. In the author's opinion, however, TQM practitioners should also be acquainted with some works of Townsend, Augustine, and Drucker.

W. Edwards Deming played a key role in spreading the use of statistical quality control in the United States during World War II. In the 1950's, American industry put their emphasis on production, forgetting much of what Deming taught. Japan, however, was rebuilding their industry based on the Deming philosophy. In 1951, the Japanese established the Deming prize, awarded every year for accomplishments in statistical application. It is still one of their most prestigious awards. The Deming philosophy is summarized in his 14 points:

1. Create constancy of purpose (for improvement)
2. Adopt the new philosophy (quality first)
3. Cease dependence on mass inspection (instead, prevent defects)
4. End awards on price alone
5. Improve the system constantly and forever
6. Institute training (of job skills)
7. Institute leadership
8. Drive out fear
9. Break down barriers between staff
10. Eliminate slogans, exhortations, and targets
11. Eliminate numerical quotas
12. Remove barriers to pride of workmanship
13. Institute a vigorous program of education and retraining
14. Take action to change

Dr. Deming also lists seven "deadly diseases" of American Management:

1. Lack of constancy of purpose
2. Emphasis on short-term profits
3. Performance reviews (which destroy teamwork and build fear)
4. Mobility of management (works against understanding and long-term efforts)
5. Running a company on visible figures alone (you can't measure the effects of a dissatisfied customer)
6. Excessive medical costs (GM's highest paid supplier is Blue Cross)
7. Excessive liability costs (America is the world leader in law suits)

Dr. Deming's advice is now in great demand in the United States. He conducts four day seminars in quality management from which two exercises, the red bead exercise and the funnel experiment, have become classic illustrations in quality training.

The red bead exercise, briefly, is a simulation of a factory. Willing workers are taken from the audience and directed to make white beads. Their process is to dip a paddle into a mixture of white and red beads. The paddle has 50 depressions and extracts that many beads from the mixture. No matter how hard the workers try, they never succeed in producing white beads without red ones mixed in. In the course of the exercise (which is far more interesting than this summary indicates) the seminar attendees learn several lessons including:

- Willing workers are doing the best they can. Exhortations and threats cannot improve quality.

- Improvements will come only by changing the process. This is management's job.

- Variation is a part of every process. It must be understood to be controlled.

In the funnel experiment, a marble is dropped through a funnel over a target. If it comes to rest away from the target, the location of the funnel is changed according to a set of rules, and another marble dropped.

One set of rules moves the funnel away from the target the same distance as the marble, out in the opposite direction. This illustrates the attempt to overcome variation by adjusting a process against the direction of error. For example, if a machine produces a rod longer than target, it would be adjusted to make shorter rods. The result of this tinkering is shown by the funnel experiment to double the variation in the product from that of a process left alone. The lesson is again to understand variation and reduce it by process changes rather than increase it by tinkering.

Another set of rules moves the funnel over the location of the marble after each trial. This compounds the errors and ultimately drives the variance to infinity. The lesson illustrated is Deming's contention that as worker trains worker more and more errors are introduced into the process. It is therefore management's responsibility to provide training and retraining in the proper methods of doing the job.

Deming also claims that quality benefits the worker as shown in the Deming Chain reaction:

IMPROVE QUALITY - COSTS DECREASE - PRODUCTIVITY IMPROVES - BETTER QUALITY AND LOWER PRICE CAPTURES THE MARKET - BUSINESS SURVIVES AND GROWS - MORE JOBS CREATED.

J. M. Juran was also an advisor to Japan, and is the author of many practical handbooks on managing quality. His philosophy is summarized in the "Juran Trilogy": quality planning, quality control, and quality improvement.

Quality planning provides the emphasis and resources to meet the customer's needs.

Quality control continuously evaluates the product and acts to prevent any degradation.

Quality improvement includes creation of an infrastructure conducive to quality improvement, chartering of project teams for specific opportunities, and supply of resources, training, and motivation.

Philip B. Crosby coined the phrase "Quality is Free" in his book of the same title. He defines quality as meeting specifications, and defines cost of quality as the expense of nonconformance including prevention, appraisal, and failure. Since the cost of failure is much higher than the cost of prevention, building in quality is less costly than not. Hence, quality is free, though not a gift.

Crosby invented the phrase "Zero defects," and proposed a 14 step approach to quality:

1. Management commitment
2. Quality improvement team
3. Quality measurement (defect rates)
4. Cost of quality evaluation
5. Quality awareness
6. Corrective action
7. Ad hoc committee for zero defects program
8. Supervisor training
9. Zero defects day
10. Goal setting
11. Error cause removal
12. Recognition
13. Quality councils
14. Do it over again

A. V. Feigenbaum coined the phrase "Total Quality Control" defined in his 1961 book "Total quality Control" as: "An effective system for integrating the quality-development, quality-maintenance, and quality improvement efforts of the various groups in an organization so as to enable marketing, engineering, production and service at the most economical levels which allow for full customer satisfaction."

Feigenbaum defined quality costs as the sum of prevention costs, appraisal costs, internal failure costs and external failure costs.

Kaoru Ishikawa in "What is Total Quality Control? The Japanese Way" emphasized:

- Leadership by top management
- Education from top to bottom
- Action based on knowledge and data
- Teamwork, elimination of sectionalism
- Customer focus
- Prevention of defects by eliminating root causes
- Elimination of inspection
- Use of statistical methods
- Long term commitment

In his book he states: "TQC is a thought revolution for management." Also, "QC brings out the best in everyone" and "When QC is implemented, falsehood disappears from the company."

Genichi Taguchi is noted for his emphasis on the reduction of variation and the creation of robust designs (i.e. designs which continue to perform well as the use environment varies). His contributions include improved methods for statistical design of experiments to determine causes of variation (though there is some controversy about these). He formulated "loss functions" to quantify the adverse economic effects of variation.

Taguchi's contributions are often explained by considering a design hierarchy: system design, parameter design, and tolerance design. System design creates the means to accomplish some mission, and American designers are strong in this area. Parameter design is concerned with the specification of the system components. This is a Japanese strength, and a Taguchi specialty. Tolerance design, the setting of limits on specified values, is done equally well by both countries.

Though not usually listed among the TQM gurus, Robert Townsend published a book, "Up the Organization," in 1970 which recognized many of the points made by the usual TQM referents. He preached rebellion against mindless rules which accumulate in all organizations. He suggested managers call their own offices to see what impressions a customer gets when he calls. He noted the importance of leadership, the need for a manager to be a coach, and the general under-utilization of people in an organization. My favorite quote:

"If you can't do it excellently, don't do it at all. Because if its not excellent it won't be profitable or fun, and if you're not in business for fun or profit, what the hell are you doing here?"

Norman Augustine wrote a book, "Augustine's Laws," describing the American aerospace industry in a way which is amusing to those who do not realize that he is not exaggerating. Some insights of interest to the student of TQM: "It costs a lot to build bad products" (cost of quality), "most of our problems are self-imposed," and "rules are no substitute for sound judgement."

Finally, Peter Drucker, the noted author of management books, ("The Effective Executive" and others) states the principle that management's job is to make a customer. He also repeatedly emphasizes that "doing things right" occupies too much management attention which should be devoted to "doing the right things." Drucker advises managers to "pick the future over the past," an excellent tenet for a TQM initiative.

Definitions of TQM.

In a draft of DoD 5000.51-G, "Total Quality Management, A Guide for Implementation" The Department of Defense states:

"Total Quality Management (TQM) is both a philosophy and a set of guiding principles that represent the foundation of a continuously improving organization. TQM is the application of quantitative methods and human resources to improve the material and services supplied to an organization, all the processes within an organization, and the degree to which the needs of the customer are met, now and in the future."

The Air Force Systems Command put out a TQM pamphlet in 1990 which defined it as:

"A leadership philosophy, organizational structure, and working environment that fosters and nourishes a personal accountability and responsibility for quality and a quest for continuous improvement in products, services, and processes.

The Air Force Electronic Systems Division's pamphlet defined TQM as:

"....The adoption of a customer-oriented operating philosophy committed to excellence in our products, services, and relationships through the total participation of all our employees in the constant improvement of all processes."

The Army Material Command uses this concise definition:

"A philosophy of pursuing continuous improvement in every process through the integrated efforts of all members of the organization"

A Navy TQM seminar offered:

"Customer-oriented, quality focused management philosophy for providing leadership, training, and motivation to continuously improve an organization's processes using modern process control techniques"

The Federal Quality Institute's definition:

"TQM is a strategic, integrated management system for achieving customer satisfaction which involves all managers and employees and uses quantitative methods to continuously improve an organization's processes."

Finally, a NASA contact provided this, by Albert M. Koller:

"TQM is an approach to managing work based upon (1) the analytical evaluation of work processes; (2) the development of a "quality" culture; and (3) the "empowerment" of employees -- all for the purpose of continuous improvement of your product or service."

Principles and Issues

From the above, we can summarize agreement on these PRINCIPLES OF TQM:

CUSTOMER SATISFACTION

MANAGEMENT LEADERSHIP CREATING A QUALITY CULTURE

IMPROVEMENT OF PROCESSES, NOT "MOTIVATION" OF PEOPLE

EDUCATION AND TRAINING (JOB SKILLS AND TQM TOOLS, AT LEAST)

DEFECT PREVENTION IN LIEU OF INSPECTION

USE OF DATA AND STATISTICAL TOOLS

TEAM APPROACH

- HORIZONTAL (BETWEEN DEPARTMENTS)
- VERTICAL (CEO TO LOWEST PAID EMPLOYEE)

CONTINUOUS IMPROVEMENT

We can also note that TQM is not: new, a program (as opposed to a process or philosophy), a quick fix or magic solution, spiritual guidance, a slogan campaign, a Japanese invention, a suggestion program, or a substitute for discipline and dedicated effort. It also is definitely not easy.

The TQM gurus are not monolithic in their opinions. There are many issues which divide them. These include:

FORMS OF RECOGNITION: Should workers who serve on improvement teams be rewarded with money? Is it better to acknowledge their contributions by a public thanks or certificate? Or should the satisfaction of making an improvement be enough?

USE OF HOOPLA: Some TQM initiatives have been kicked off with parades. Banners and coffee mugs with TQM slogans abound. Crosby would recommend these; Deming might consider them empty exhortations. Who is right, or does it depend on the organization?

SETTING GOALS: Is this an essential activity or a counterproductive exercise? Motorola's so far successful "six-sigma" program has a yearly target for defect reduction. Deming might point out that an easy approach to victory would be to change the definition of defect (something not unknown in my bureaucracy). Does it take a target to sustain energy, or is it an invitation to play numbers games?

"ZERO DEFECTS": Where ZD has not been successful, it is called an empty slogan. As an exhortation for willing workers to do better, it would be just that. However, it is a concise summary of the goal of all TQM effort. Since it represents an unattainable perfection, it implies the need for constant improvement. The difference in these two viewpoints may be merely a reflection of the understanding with which a ZD program is applied. (Note that Crosby advocates ZD as a program rather than a philosophy; he achieves constancy of purpose by repeating the program yearly.)

APPRAISALS: Despite Deming's condemnation, performance appraisals are likely to be with us a while. Can we live with them? Can we make them useful (by appraising teamwork, for example)?

TEAMS: Should participation on improvement teams be voluntary or mandatory? Who charters a team? At the Harris Corporation in Melbourne, FL, each activity in the plant is designated a "work cell" and its employees assigned to a quality improvement team with a goal formulated by management. This is in addition to cross-functional teams created at higher levels for ad hoc missions. In some agencies, teams are chartered by a TQM Council, and membership assigned to agencies, if not individuals. At the Rome Laboratory, any level of management can charter a team, and membership is strictly voluntary. What's best for your activity?

SUGGESTION BOXES: Often established to get the voice of the employee. Can deteriorate into a means for venting frustration (perhaps a useful function). However, usually a one-way street; the employee does not get feedback on what was done with his input. Unless visible action is taken in a timely manner, the worker may assume that no one is paying attention. Since not all suggestions can be implemented, the lack of feedback may give an impression of a lack of management support, even when it exists.

IMPLEMENTING TQM

The following is a summary of actions recommended to make TQM happen:

1. CREATE VISION (What do you want to be? Consider both goals and values.)
2. PLAN ACTION (How do you get from today to the vision?)
3. CREATE STRUCTURE
 - INSTITUTE TRAINING
 - ELIMINATE HASSLES
 - INVOLVE EMPLOYEES
 - TRUST AND EMPOWER THEM
 - PERMIT RISK TAKING
 - "WALK THE TALK"
 - ALWAYS PUT QUALITY FIRST
 - MAKE APPRAISAL/REWARD SYSTEMS SUPPORTIVE
 - CREATE CROSS-FUNCTIONAL TEAMS
4. MEASURE PROGRESS
5. UPDATE PLANS AND VISION AS REQUIRED.

In implementing TQM, the chief executive officer must lead the way. He cannot delegate leadership, nor can he ever put quality on the back burner, or TQM will never mature at his agency.

If a union represents the employees, they must become partners in TQM implementation. They should be involved at the start and all TQM information must be shared with them. The union should define its own role in TQM, but it should be separate from established grievance and bargaining procedures.

An aggressive training program is necessary to deploy the vision and create a quality culture. Job skills and basic quality concepts must be provided to all employees. Those involved in improvement teams should have available to them training in group dynamics and in TQM analysis tools of interest.

Improved quality must never be seen as a threat. When an improved process needs less man-hours to perform, the people released should be considered an asset available for other uses and guaranteed continued employment.

TQM has been described as a cultural change. The following is an Air Force chart illustrating this idea.

CULTURAL CHANGES NEEDED

<u>FROM</u>	<u>TO</u>
BOTTOM LINE EMPHASIS	QUALITY FIRST
MEET SPECIFICATION	CONTINUOUS IMPROVEMENT
GET PRODUCT OUT	SATISFY CUSTOMER
FOCUS ON PRODUCT	FOCUS ON PROCESS
SHORT TERM OBJECTIVES	LONG TERM VIEW
DELEGATED QUALITY RESPONSIBILITY	MANAGEMENT-LED IMPROVEMENT
INSPECTION ORIENTATION	PREVENTION ORIENTATION
PEOPLE ARE COST BURDENS	PEOPLE ARE ASSETS
SEQUENTIAL ENGINEERING	TEAMWORK
MINIMUM COST SUPPLIERS	QUALITY PARTNER SUPPLIERS
COMPARTMENTALIZED ACTIVITIES	COOPERATIVE TEAM EFFORTS
MANAGEMENT BY EDICT	EMPLOYEE PARTICIPATION

This chart can be used as a statement of goals and as a check list to gauge progress.

TQM TOOLS

This section will discuss TQM tools including the basic analytical tools, statistical process control, advanced analytical tools, special tools used by teams, and action plans for improving processes.

BASIC ANALYTICAL TOOLS

First, let's look at the most basic tool of all: the question "why?" Many TQM references list a technique called "The five whys." Actually, five is used just for convenience; the method is simply to get to the root cause of a problem by asking "why" as often as necessary. For example:

Why is our mail from our customer in Oshkosh so slow?

It's held up in the mailroom.

Why?

The mail people have to look up our mail code.

Why?

Our customer doesn't put it in our address.

Why?

He doesn't know it.

Why?

We never told him. (root cause - corrective action can be taken)

Ishikawa contends that 95% of a company's problems can be solved with the use of seven basic tools. Only one of these, control charts, is of any great complexity. The author believes any engineer can look at a sample of the other six and immediately understand how to use them. The seven basic TQM tools are also popular in the literature. However, every citation seems to differ from the others by one tool. Here's mine:

THE SEVEN BASIC TOOLS:

- flow charts
- Ishikawa diagrams
- checklists
- histograms
- Pareto charts
- scattergrams
- control charts

This list differs from Ishikawa's in that I substituted flow charts for stratification (which I will include in my discussion of Pareto charts). A flow chart is simply a diagram showing the inputs and outputs of all operations in a process. (see figure 1.) Strictly speaking, it should also

show feedback, which is a part of every process. It is a fundamental tool in that it provides understanding of the process under study. It is important that the actual process be captured, not the manager's uninformed opinion of what is happening. Very often, the actual process is not what the manager thought it was and an accurate flow chart makes many corrective actions obvious.

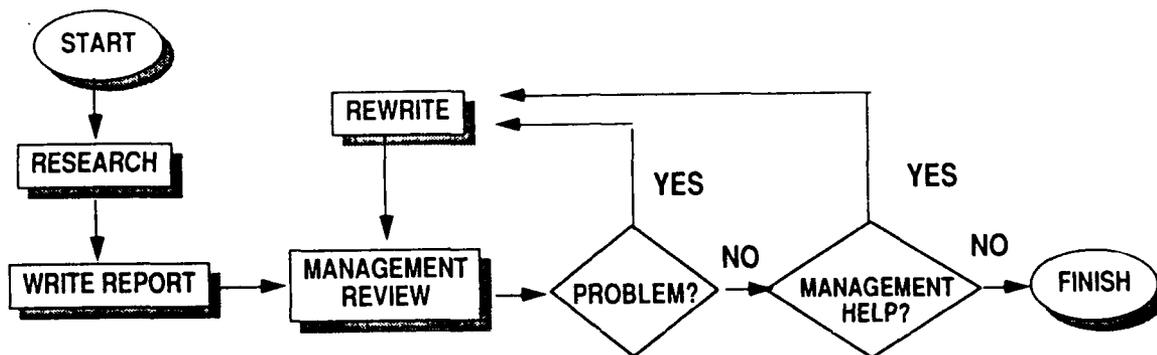


Figure 1

An Ishikawa diagram is also called a cause and effect chart or, from its form, a fishbone chart. (see figure 2.) It simply displays the factors which cause an effect such as a problem under study or a goal to be worked for. The "bones" of the chart can be any set of factors considered important as causes. Often it is helpful to start with the "4 M's" : METHOD, MANPOWER, MATERIAL, MACHINERY; or the "4 P's": POLICIES, PROCEDURES, PEOPLE, PLANT. Each "bone" can have any number of subordinate bones, and each subordinate bone can also have any number of subordinates, etc. The purpose of the chart is to isolate the factors which can then be worked on to solve the problem or reach the goal they help cause.

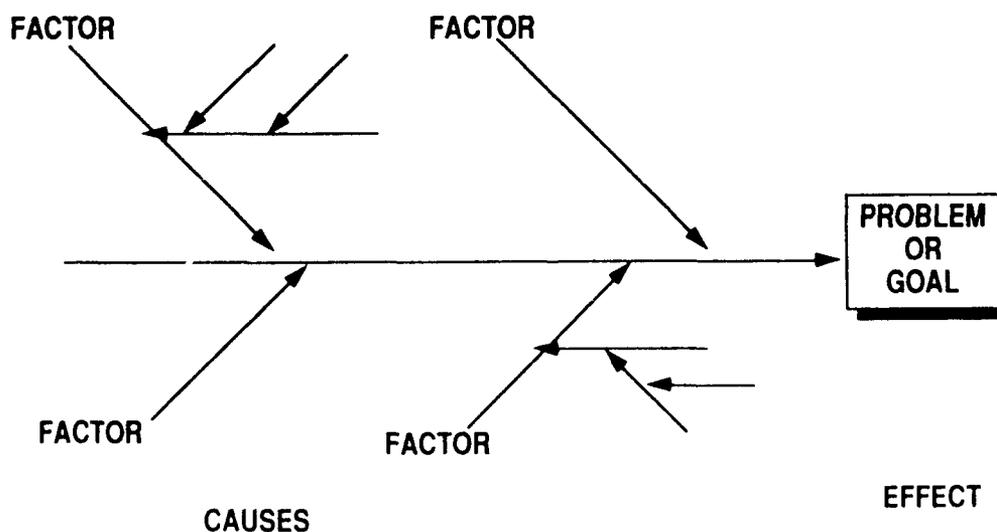


figure 2

Checklists are simply a means of collecting data. The idea is to record happenings as they occur against a list of possible events. This provides factual, rather than anecdotal, evidence of what is really happening. (see figure 3.)

DEFECT	M	T	W	TH	F	TOTALS
A	I	I			I	3
B	II	I	II	I	I	7
C		I	I		I	3

Figure 3

Histograms are used to show the distribution of outcomes of a repetitive event. Figure 4 shows the typical normal distribution of an event such as the length of rods produced by a machine. Of interest would be the mean and variation shown by the histogram. Figure 5 shows a bi-modal distribution, which indicates that the output charted comes from two separate processes (two machines, two shifts, two stocks of raw material, etc.) whose products are mixed.

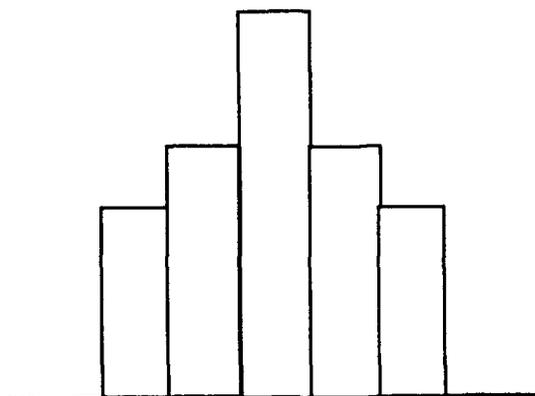


Figure 4

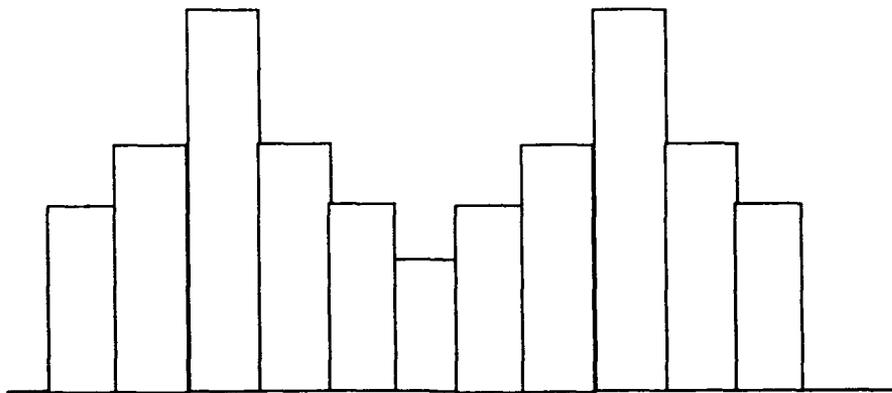


Figure 5

Pareto charts show graphically the relative magnitude of output from different factors. Figure 6 is an example of injuries separated by location. Pareto charts can be nested; the largest output on one chart is separated on another Pareto chart as figure 7 separates the causes of the eye injuries shown of figure 6. Also, Pareto charts can be used for stratification. The same data is plotted on several charts which separate it by different factors. For example, figure 8 shows the number of defects to relate to product line rather than factory or shift.

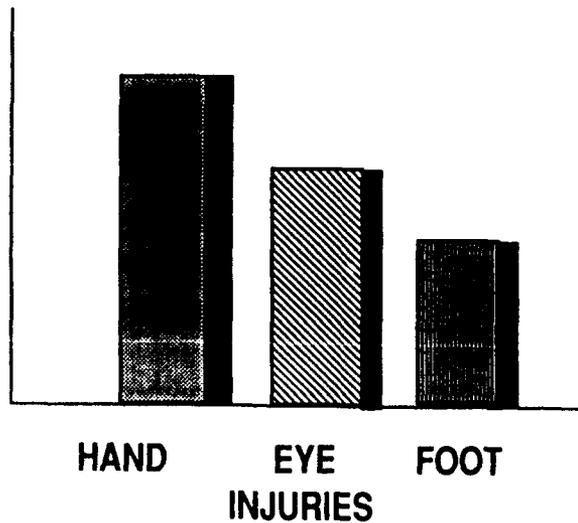


Figure 6

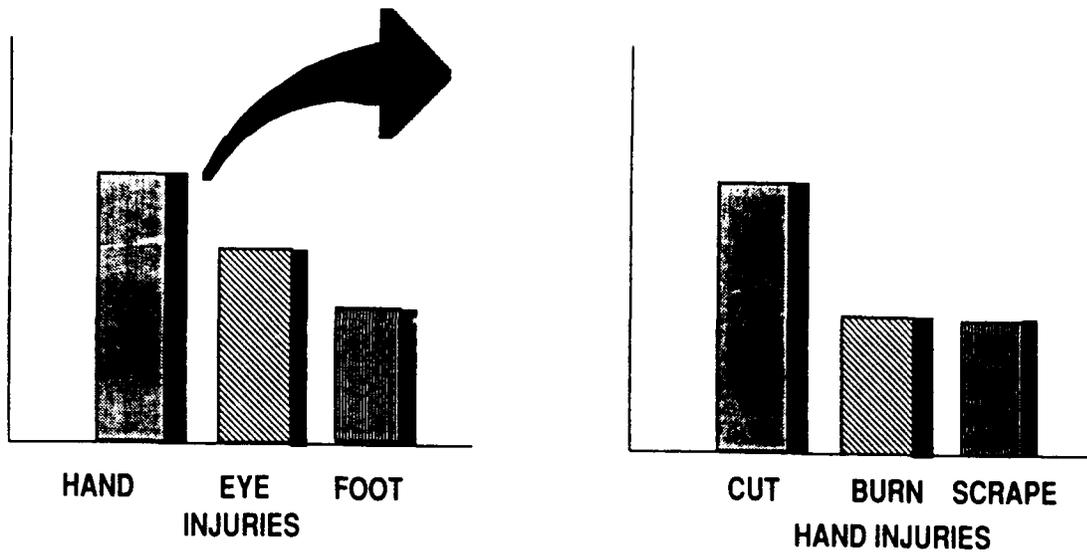


Figure 7

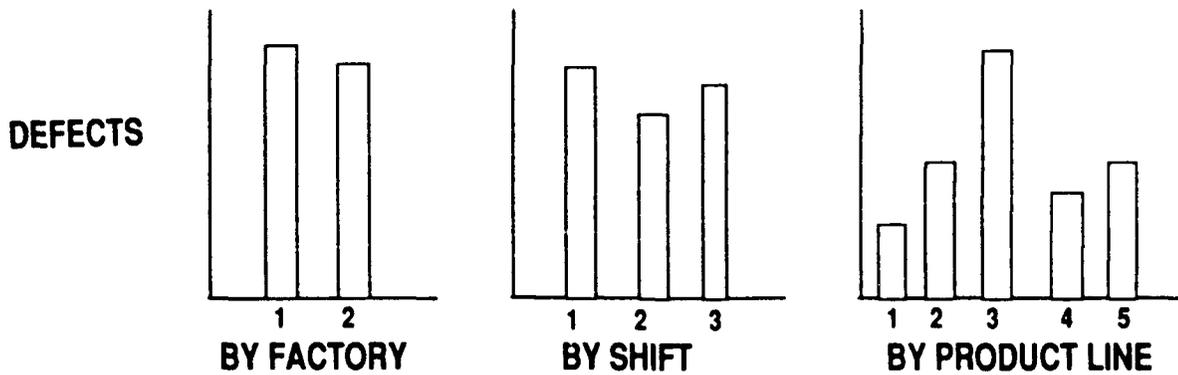


Figure 8

Scattergrams are simply a test for correlation between two factors. Data is gathered and for each point, the value of one factor is plotted horizontally and the other vertically. If the resultant cloud of dots clusters around a line, correlation is indicated. (See figure 9.)

Control charts, the last of the basic tools, will be covered in a following discussion of statistical process control. Before that, there are some other simple tools I would like to present.

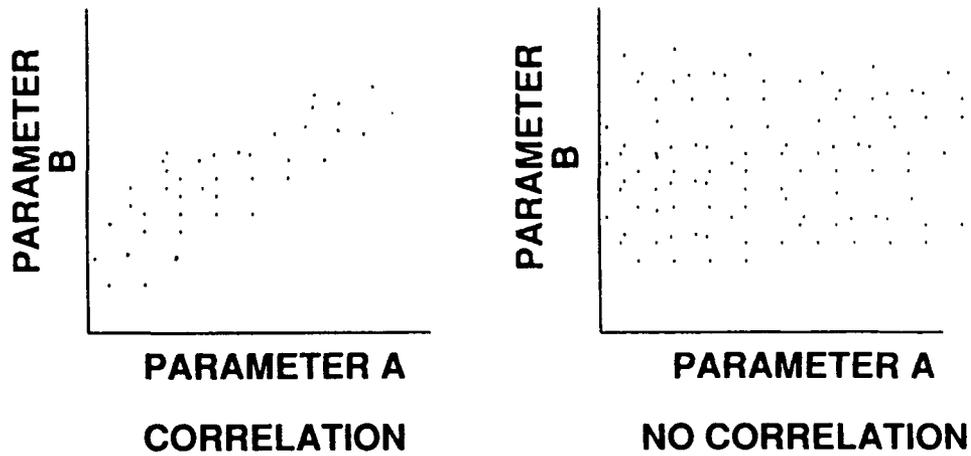


Figure 9

A force field simply plots the forces which support and oppose some effect. Like the Ishikawa diagram, its purpose is to identify causal factors for further analysis as candidates for change to increase or decrease the probability of the effect happening. (See figure 10.)

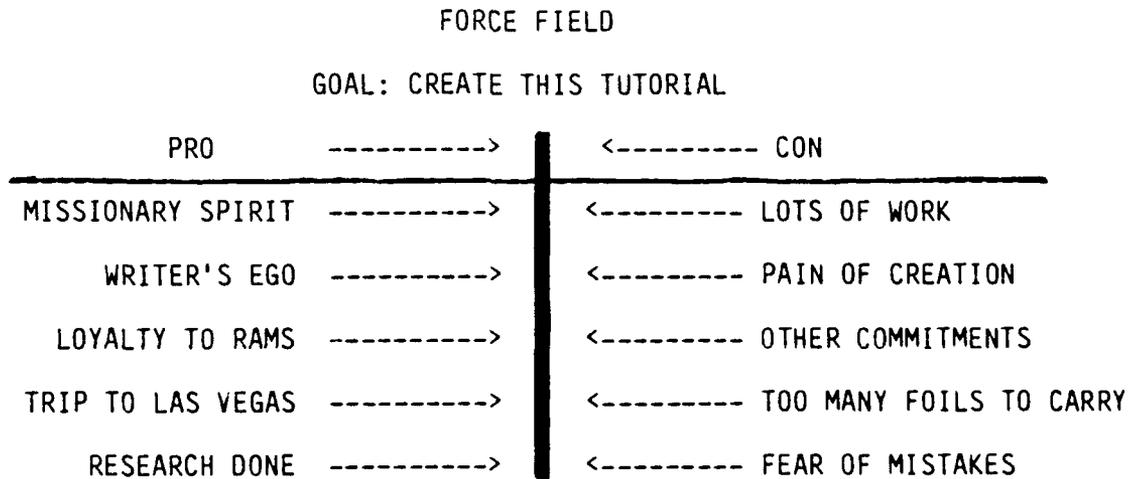


Figure 10

A "measles" chart is a graphic form of check list showing the locations of some event of interest. Figure 11 shows the locations of failures on a printed circuit card.

A run chart plots data against a time scale to show trends and periodic effects. (See figure 12.)

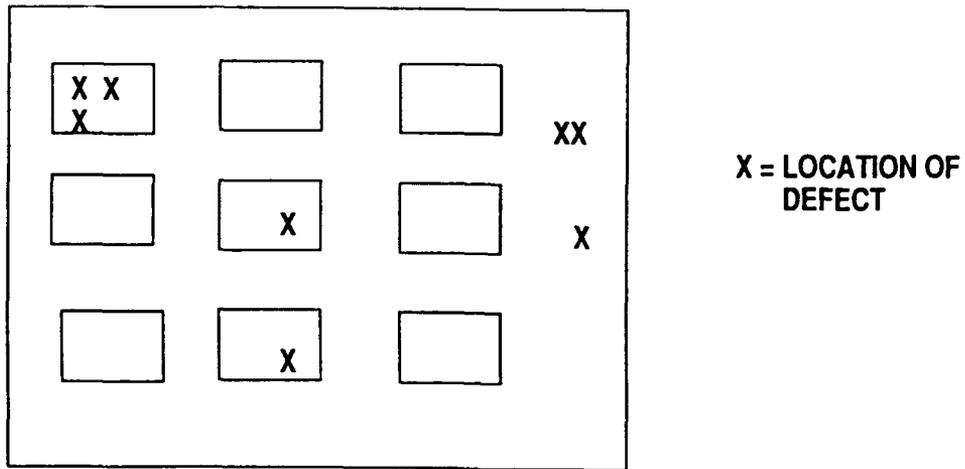


Figure 11

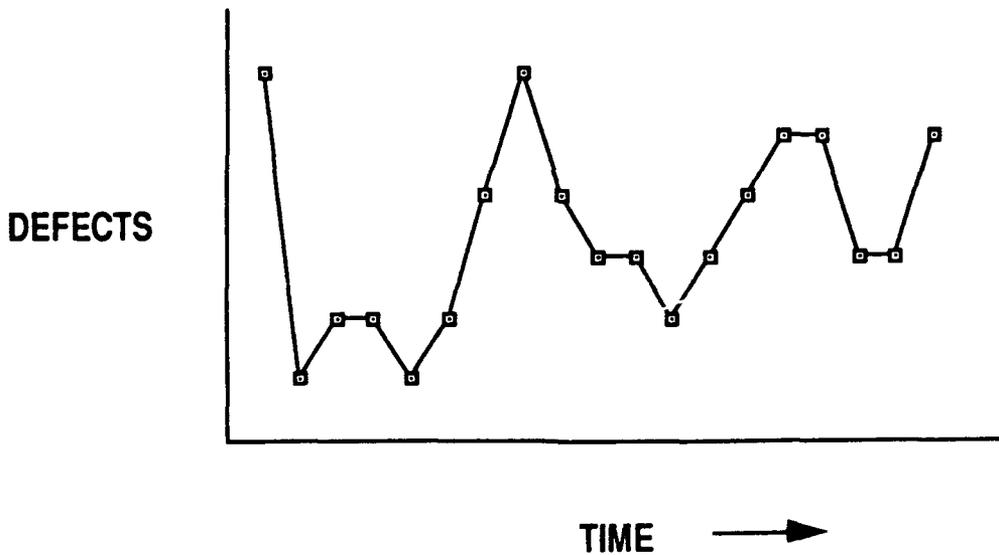


Figure 12

None of the tools so far described are difficult to understand. However, statistical process control does take some explaining.

STATISTICAL PROCESS CONTROL

Statistical process control recognizes that every process has some variation. "Common cause variation" is random and predictable and describes the variation inherent in a process. Hence it cannot be reduced without a process change. "Special cause variation" is variation outside that expected for a process and hence due to some special cause which can be isolated and eliminated. The process is "in control" when measurement show only common

cause variation. Note that "in control" does not necessarily mean the process is producing products in specification. It can be in control and also not capable of producing the desired products. If so, only a better process can provide the desired product; a process in control is doing the best it can.

If samples taken from a process in control are measured, the central limit theorem states the overall mean of the means of the samples will equal the process mean, and the sample means will be normally distributed, which implies that 99.7% of the sample means will be within three standard deviations of the overall mean. Therefore, when sample means vary randomly within three standard deviations, the process is in control. Otherwise corrective action may be required to eliminate a special cause of variation.

Figure 13 shows a generic control chart. The center line is the expected process mean (or the specified target value). The upper control limit (UCL) is the mean plus three standard deviations of the sample data (sigmas), and the lower control limit (LCL) the mean minus three sigmas. (Note: If the LCL computation produces a negative number, the LCL is set to zero.)

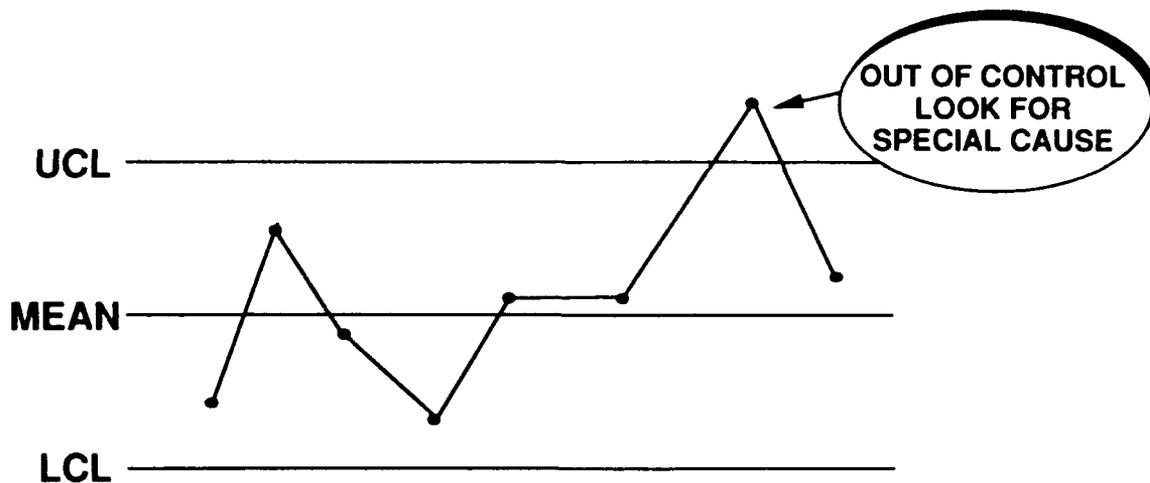


Figure 13

Sigma is computed from the sample data. It will be a function of the sample size and the standard deviation of the process. The computation differs depending on whether the parameter of interest is a variable, an attribute, or a rate.

Controlling Variables

A variable is a measured parameter such as the length of a rod. For that case, the centerline of a control chart would be the mean rod length (population mean estimated from a series of samples or the target mean). In addition, a second control chart, the range chart, would probably be used to record the variations in length between rods.

Using rod lengths for illustration, parameters of interest for variable and range charts would be:

X_i = length of one rod

n = number of rods in one sample

\bar{X} = mean of sample = $\sum X_i/n$ = one point on the control chart

k = number of samples over a reasonably long time period

$\bar{\bar{X}}$ = mean of process = $\sum \bar{X}/k$ (if all samples are equal) = centerline

R_i = range of one sample = highest X_i - lowest X_i

\bar{R} = average range = $\sum R_i/k$ = centerline of range chart

In basic form, the variable or \bar{X} chart has a centerline of $\bar{\bar{X}}$, and the control limits are given by the following formulas:

$$UCL = \bar{\bar{X}} + 3 S' / \sqrt{n}, \quad LCL = \bar{\bar{X}} - 3 S' / \sqrt{n}$$

where: S' = population standard deviation

$$S' = \sqrt{\frac{1}{n-1} \sum_1^n (X_i - \bar{X})^2}$$

OR: $S' = S/c$

where: S = sample standard deviation

$$S = \sqrt{\frac{1}{n} \sum_1^n (X_i - \bar{X})^2}$$

and: c = a constant dependent on sample size, shown in table 1.

Using range data simplifies computations. When an average range (\bar{R}) is obtained from a long series of samples, the control limits on the \bar{X} chart are:

$$UCL = \bar{\bar{X}} + A_2 \bar{R}, \quad LCL = \bar{\bar{X}} - A_2 \bar{R}$$

where: A_2 is taken from table 1.

The range (R) chart is concerned with the variance between parts rather than between the sample means. For the R chart:

$$\text{Centerline} = \bar{R}, \text{ UCL} = D_4 \bar{R}, \text{ and LCL} = D_3 \bar{R}$$

where: D_4, D_3 = constants obtained from table 1.

CONTROL CHART CONSTANTS

n =	2	3	4	5	6	7	8	9	10	12	15	20
c =	.56	.72	.79	.84	.87	.89	.90	.91	.92	.94	.95	.96
A_2 =	1.88	1.02	.73	.58	.48	.42	.37	.34	.31	.27	.22	.18
D_3 =	0	0	0	0	0	.08	.14	.18	.22	.28	.35	.41
D_4 =	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78	1.72	1.65	1.59

Table 1

Controlling Attributes

An attribute is a feature of a product which is either present or not, such as a defect. To control attributes, the centerline of the chart is set equal to (\bar{p}) , the proportion of the product with the attribute, estimated from many samples. The control limits are given by:

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad \text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

When sample size is fixed at (n), the centerline can be set to (np) which is the mean number of items with the attribute in a sample of n units. Using np as the centerline:

$$\text{UCL} = n\bar{p} + 3\sqrt{n\bar{p}(1-\bar{p})} \qquad \text{LCL} = n\bar{p} - 3\sqrt{n\bar{p}(1-\bar{p})}$$

Controlling Rates

To control rates, such as defects per aircraft, or defects per 100 feet of wire, etc., the centerline of the chart is set to (r), the mean rate estimated from a lot of data. Then:

$$UCL = r + 3\sqrt{r} \qquad LCL = r - 3\sqrt{r}$$

For rates without constant sample sizes, such as the number of defects per unit in a variable monthly production, the centerline would be (u) which is the mean rate per unit, and:

$$UCL = u + 3\frac{\sqrt{u}}{\sqrt{n}} \qquad LCL = u - 3\frac{\sqrt{u}}{\sqrt{n}}$$

n = units in sample. Note that the control limits may change from sample to sample if n is not constant.

ADVANCED ANALYTICAL TOOLS

This section will very briefly discuss some of the advanced analytical methods associated with TQM. Quality function deployment (QFD) and the statistical design of experiments (DOE) will be described. Then we will look at some of the contributions of Genichi Taguchi.

Quality Function Deployment

QFD is based on a matrix comparing "whats" to "hows." The "whats" are the customer's requirements and the "hows" are the organization's responses. For example, figure 14 shows the desired attributes of a fighter plane against the design factors which may have an impact. In the matrix are symbols showing the relationship, if any, between each item on the two lists. The matrix highlights the important "hows," with figure 14 showing shape to be critical and the plant site to be unimportant in meeting the list of "whats."

This simple matrix can be cascaded and/or expanded to provide additional information.

Cascading the QFD matrix means making the "hows" of one matrix the "whats" of a subordinate matrix. In figure 15, the first matrix translates customer specifications (top level "whats") into design solutions ("hows"). These design solutions become the "whats" of the next matrix matched against "hows" in terms of the parts used. The next tier matches the parts against the processes. The final matrix matches the processes against process parameters. Hence, there is a defined trail leading from the customer's specifications to such details as the size of a spray paint nozzle. The trail followed need not be the one described in figure 15, so long as the requirements are decomposed in a logical fashion from the top level "whats" to the detailed process "hows."

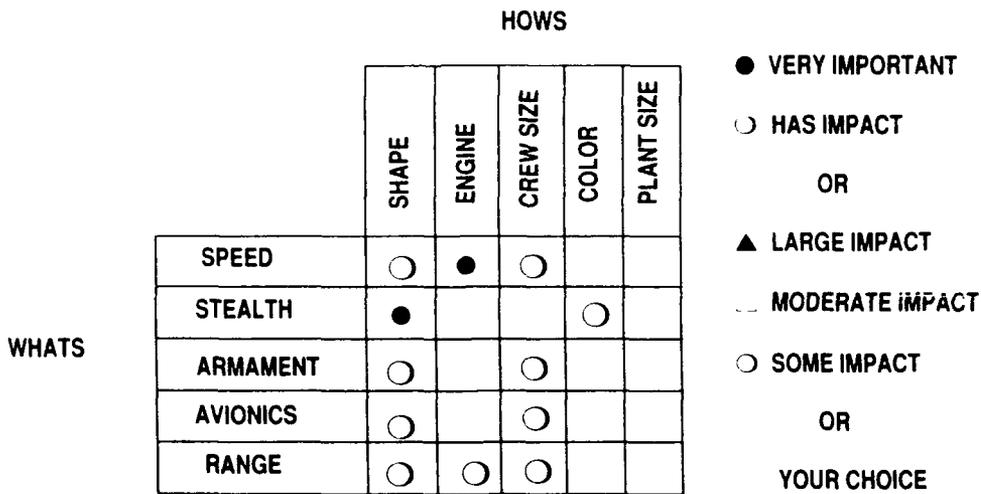


Figure 14

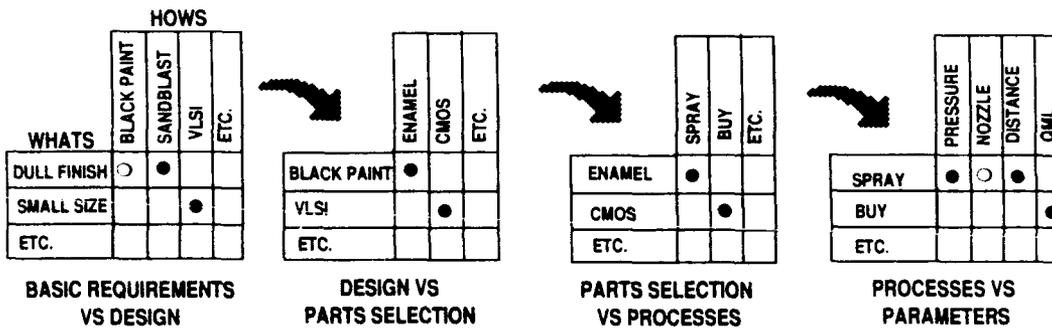


Figure 15

Expanding the QFD matrix means adding more details of interest. One obvious detail is the priorities of the customer, which can be added to the "whats". A summary rating of the importance of each "how" would seem useful and can be added to the "how" columns, along with target values, estimated difficulty, etc. Benchmarks of our organization's capability for meeting the "whats" and our competitor's capabilities could be added. Since the "hows" are not independent (one design feature can reinforce or diminish the effects of another), the relationship between "hows" could be worth displaying. Figure 16 shows one version of a "house of quality," so called because of the shape resulting from expanding the QFD matrix. Figure 17 shows the house of quality for this tutorial. Expanded QFD matrixes such as the house of quality can also be cascaded.

QFD requires a lot of effort. Essentially, it invests time in planning to reap a profit in the design phase for an overall shorter development cycle. It also minimizes the need for redesign, which can dramatically shorten the overall time from start to production. The exercise of working with your customers to define their desires and priorities before you go charging off to design the solution is always extremely useful, whether you use a simple matrix or a "mansion of quality."

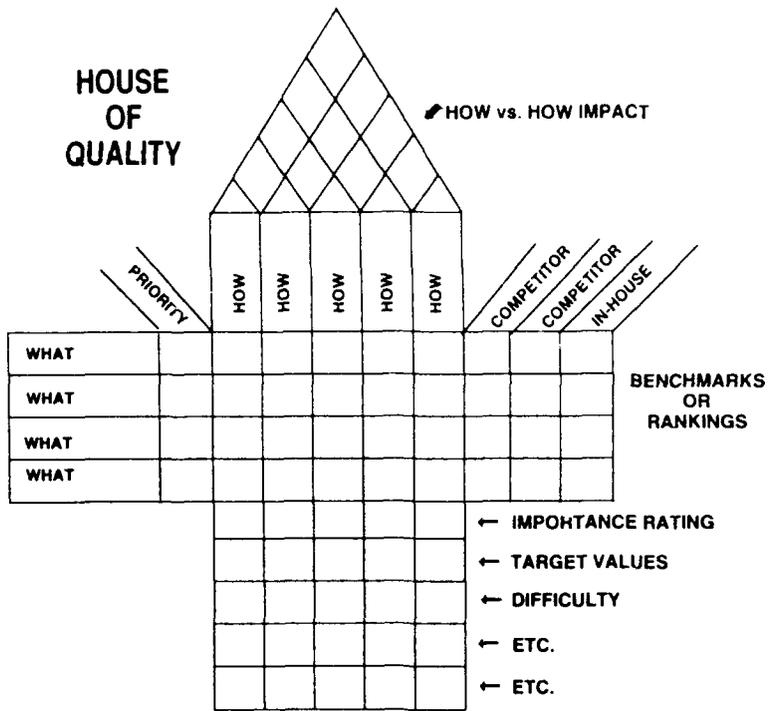


Figure 16

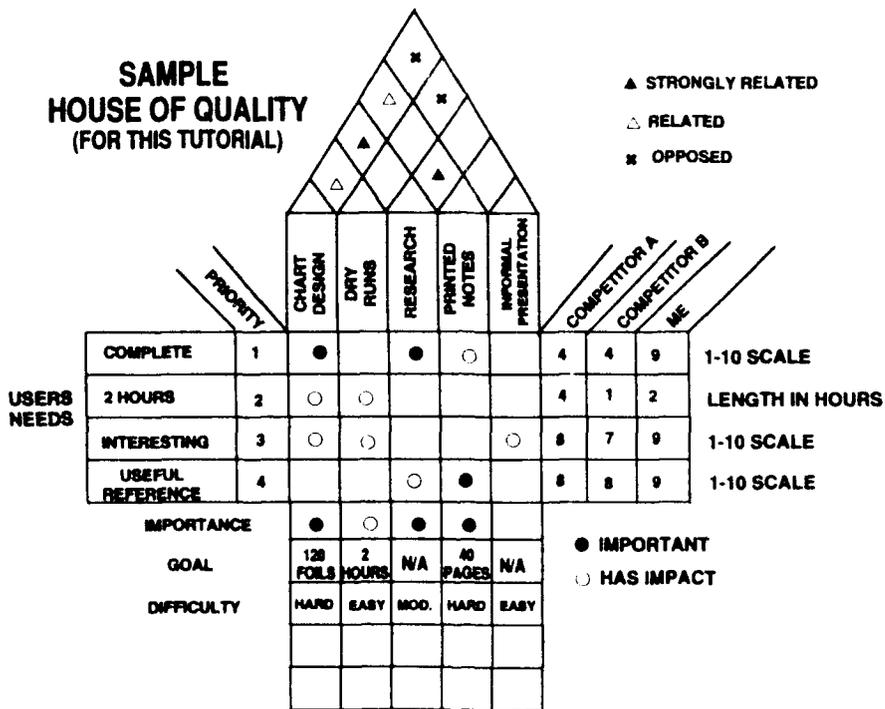


Figure 17

Statistical Design of Experiments

Statistical design of experiments (DOE) is an organized approach to determining the effects of process parameters on its output. For example, we could do experiments on soldering with temperature, solder tin-lead ratio, wave machine height setting, etc. as test factors and the solder defect rate as output. From this, we wish to determine the setting for each factor which will give us the lowest defect rate. There are many different ways we could run tests, ranging from varying one factor at a time to complex combinations of factors and setting. DOE procedures are designed to provide results which are statistically valid, unambiguous, and economical. The general procedure is:

1. Select factors. It is not always obvious which factors are important. Factors are often selected after a brainstorming session has filled in an Ishikawa chart, and the team involved has ranked the hypothesized causal factors in their consensus of priority.
2. Select test settings: Usually, a high and low setting are selected. For something like the presence or absence of a factor, the high setting is present and the low factor, absent. Some items cannot be done in two settings. For example, we may have five different fluxes we can put in the solder. This requires five "settings," at least. While DOE can handle such cases, this discussion will be limited to two value experiments.
3. Set up an appropriate orthogonal array. An orthogonal array balances the test settings so that, for example, factor A is tested at both high and low settings of factor B, so that the effects of factor B will not confuse our evaluation of factor A. In addition, interactions between the factors can be easily determined. Figure 18 is an example of a two factor orthogonal array. Note that the high setting for each factor is represented by a plus sign and the low factor by a minus sign. This is shorthand for plus one and minus one, because the high and low values of each factor are coded as plus and minus one. (e.g. temperature of 200 degrees is -1, 400 degrees is +1; switch off is -1, on is +1; etc.) This permits some computational shortcuts.

RUN	FACTORS (TEST SETTINGS)		INTERACTION (CALCULATED)	RESULTS (MEASURED)
	A	B	A · B	
1	- (LOW SETTING)	-	+	Y_1
2	+ (HIGH SETTING)	-	-	Y_2
3	-	+	-	Y_3
4	+	+	+	Y_4
AVG -	$\frac{Y_1 + Y_2}{2}$	$\frac{Y_1 + Y_3}{2}$	$\frac{Y_2 + Y_3}{2}$	$\bar{Y} = \frac{Y_1 + Y_2 + Y_3 + Y_4}{4}$
AVG +	$\frac{Y_2 + Y_4}{2}$	$\frac{Y_3 + Y_4}{2}$	$\frac{Y_1 + Y_4}{2}$	
Δ	(AVG +) - (AVG -)			

$$Y = \bar{Y} + \frac{\Delta^A}{2} A + \frac{\Delta^B}{2} B + \frac{\Delta^{A \cdot B}}{2} A \cdot B$$

Figure 18

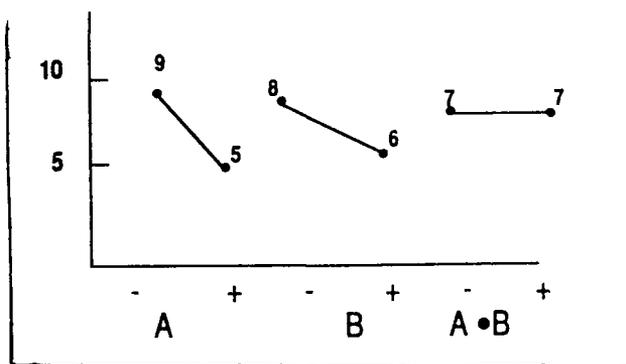
3. Run the tests. The tests can be run once at each setting shown in the rows of the array, or multiple times to gather information on the variability of the measured results.

4. Analyze the results. The difference in output for different factor settings can be measured and charted. For the examples shown here, it is also easy to create a regression equation which will permit the determination of optimum settings at points not actually tested. The regression formula is shown in figure 18, and figure 19 shows some possible results. It is assumed that the effects of the factors are linear over the range tested.

5. Calculate optimum settings. The regression equations in figure 19 show an example of this for maximum, minimum and target values.

6. Do confirmation run test. Since there may be important factors not considered or non-linear effects, the optimum settings must be verified by test. If they check out, the job is done. If not, some new tests must be planned.

RUN	A	B	A•B	Y
1	-	-	+	10
2	+	-	-	6
3	-	+	-	8
4	+	+	+	4
AVG -	9	8	7	$\bar{Y} = 7$
AVG +	5	6	7	
Δ	-4	-2	0	



$$Y = 7 - 2A - B$$

FOR MAX Y, SET A, B TO -1 (LOW SETTING)

FOR MIN Y, SET A, B TO +1 (HIGH SETTING)

FOR Y = 5 SET A TO +1 (HIGH SETTING)

B TO 0 (MIDWAY BETWEEN HIGH & LOW)

Figure 19

Taguchi Methods

Modifications to DOE are a specialty of Genichi Taguchi, who uses a modified array and analyzes output based on a "signal to noise ratio" which is in turn based on a "loss function" relating variability in a product to economic loss in its use. Figure 20 shows a Taguchi array. A notational difference between figures 18 and 20 is that Taguchi uses 1 and 2 where others might use -1 and +1 for the lower and upper settings. The significant difference, however, is that the column used for interaction data has been replaced by another factor, factor C. Taguchi assumes the interaction between factors will usually be negligible and hence the confounding of interaction data with factor data will be no problem. This permits three factors to be tested where only two could be before. This economy compounds with the number of factors. For n factors the orthodox array needs a number

of test runs equal to two raised to the nth power. In that many runs, the Taguchi array can test a number of factors equal to one less than the number of runs. Figure 21 shows the difference in eight runs. This economic advantage is significant; the risk is that interactions may prove to be important. Figure 22, for example, show a drastic interaction between factors A and B. If a Taguchi array were used, the interaction effects would be attributed to factor C in addition to any effects that C caused itself. (The error would presumably be found after a confirmation run failed.)

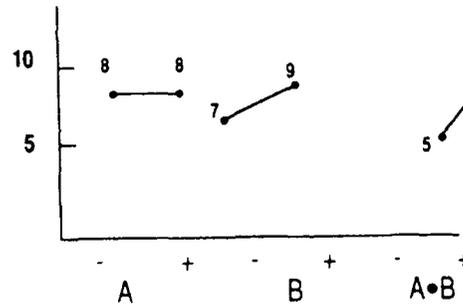
RUN	A	B	C	Y
1	2	2	1	
2	1	2	2	
3	2	1	2	
4	1	1	1	

Figure 20

RUN				(D)	(E)	(F)	(G)
	A	B	C	A•B	A•C	B•C	A•B•C
1							
2							
3	3 FACTORS TESTED USING ORTHODOX ORTHOGONAL ARRAY			ALL INTERACTIONS VISIBLE USING ORTHODOX ARRAY OR 4 ADDITIONAL FACTORS TESTED USING TAGUCHI ARRAY			
4							
5							
6							
7							
8							

Figure 21

RUN	A	B	A•B	Y
1	-	-	+	10
2	+	-	-	4
3	-	+	-	6
4	+	+	+	12
AVG -	8	7	5	Y = 8
AVG +	8	9	11	
Δ	0	2	6	



$$Y = 8 + 0 + B + 3 (A \cdot B)$$

Figure 22

Instead of the measured output data from an experiment, Taguchi recommends the use of logarithmic transformations which consider both the mean values and variability. These "signal to noise ratios" are shown in figure 23.

SMALLER IS BETTER

$$S/N_S = -10 \text{Log}_{10} \frac{1}{n} \sum_{i=1}^n (y_i^2)$$

LARGER IS BETTER

$$S/N_L = -10 \text{Log}_{10} \frac{1}{n} \sum_{i=1}^n \left(\frac{1}{y_i^2}\right)$$

NOMINAL IS BETTER

$$S/N_N = 10 \text{Log}_{10} \frac{1}{n} \left(\frac{S_m \cdot V_e}{V_e}\right)$$

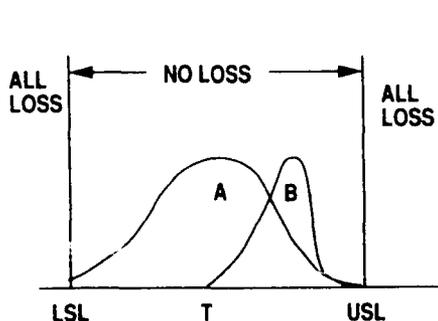
where $S_m = \frac{(\sum y_i)^2}{n}$ and $V_e = \frac{\sum y_i^2 \cdot (\sum y_i)^2}{n \cdot (n-1)}$

y_i = ONE OBSERVATION

n = NUMBER OF REPLICATIONS OF TEST RUN

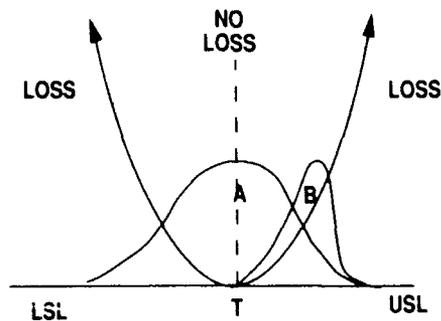
Figure 23

The use of signal to noise ratios (S/Ns) requires replicated runs to obtain the variability data. The factor making the largest change in the S/N is considered the most important factor to control in order to minimize loss, since loss is related both to mean value and variability of the output. This is according to Taguchi's loss functions. The basic premise of loss functions is shown in figure 24, which compares the traditional concept of specifications to the loss function.



"GOALPOST" CONCEPT

ALL PRODUCT BETWEEN USL & LSL IS GOOD



LOSS FUNCTION

**WIDE VARIATION IN PRODUCT IS BAD
MEAN OFF TARGET IS BAD**

Figure 24

The loss functions themselves are shown in figure 25. In theory, it is possible to compute a dollar loss from the distribution of the products.

This can be a loss to the producer from rejects or rework, or a loss to society from the effects of variation. The author accepts the concept, but would be leery of any computed dollar loss values.

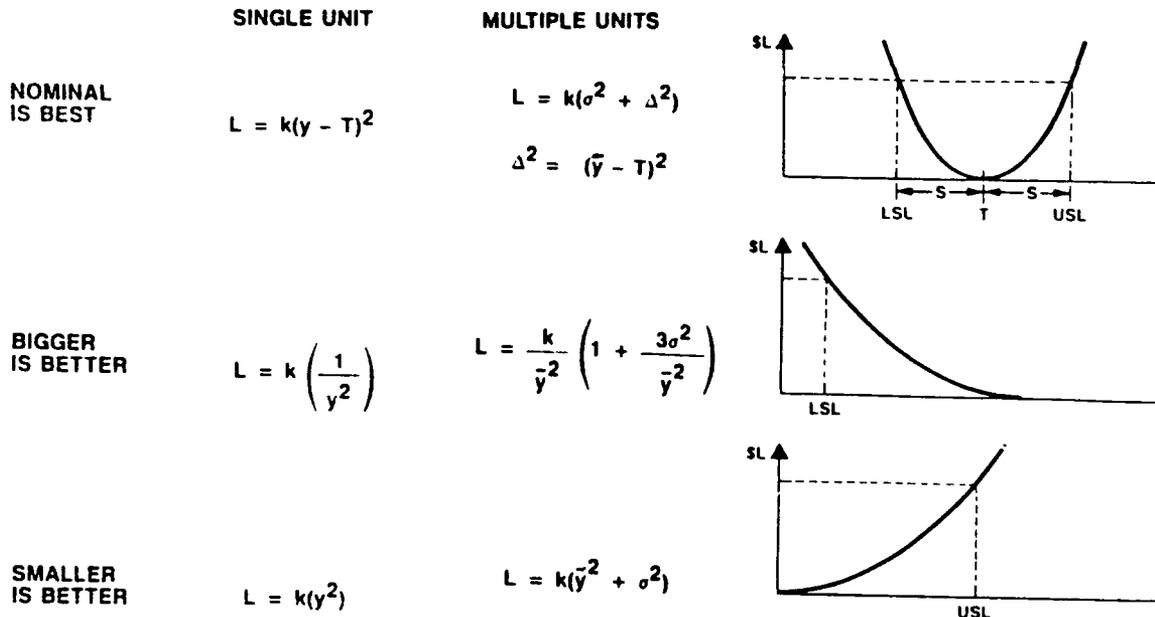


Figure 25

TEAM TOOLS

The use of teams to improve an organization's processes is a basic tenet of TQM. Whether called Process improvement teams, process action teams, Delta teams, or (erroneously) quality circles, the objective of the team is to improve quality by changing a process. It is possible to start a team by merely convening a bunch of people and giving them an objective. For best results, however, the team should have some knowledge of the quality concepts and basic analytical tools described above. It also helps to have some knowledge of group dynamics (how teams work), some tools to evaluate their team process, and some tools that the team can use in performing their process. This section will discuss teams and their tools, finishing with some advice on getting started with team activity. Incidentally, the quality circle was invented in Japan as a means of educating employees in the concepts of quality, with improving processes as a secondary objective. Hence the significance of the improvements is not terribly important and the members of the circle are typically from a single office. In contrast, the improvement team's main function is to make significant changes in an agency's processes; hence there is more concern for the payoff and, typically, a multi-office membership. The team is more likely to be an ad hoc effort which disbands after the project is completed while the circle continues with another project. The Harris Corporation's "Employee Improvement Teams" do seem to be a hybrid: They are single "work cell" entities, and permanent teams with sequential projects, but the projects are assigned by management, presumably with significant benefits the main goal. (Harris also used multi-office "System Improvement Project" teams on an ad hoc basis.)

TEAM DYNAMICS

Figure 26, or version thereof, is a common description of the phases a team goes through. It is called the team wheel or team clock.

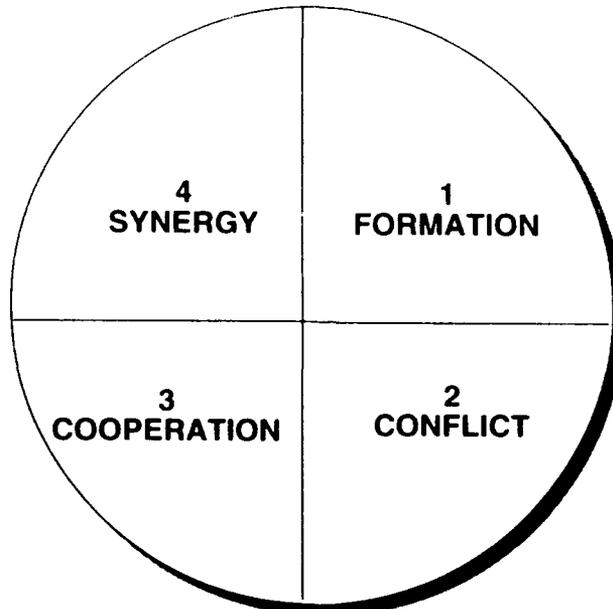


Figure 26

What the wheel indicates is that a newly formed team goes through a formation phase where it tries to establish its goals and working procedures, and each member tries to assess his (or her) value to the team and the team's value to him. This can lead to conflict as the goals of the team members probably will not agree. Conflict is not necessarily bad, if it is addressed with good will and resolved to create a cooperating team. When a cooperating team has evolved, the members have a sense of fellowship and work effectively towards their goal. After this, there may be periods of synergy, when the group works with high creativity, and the individual members feel a great sense of loyalty to the group and a keen enjoyment of the group process. It is generally the best state to be in, but there is a potential dark side, called "groupthink." This state is characterized by a feeling of invincibility in the group and a tendency to submerge any individual reservations about group decisions, sometimes leading to fantastically gross errors. However, so long as the group keeps touch with reality and discusses issues thoroughly, they will make their best contributions while enjoying the natural high of synergy.

Team Roles

Members of a team will have differing personalities, and this diversion is a source of team strength. Students of group dynamics have created various taxonomies to describe the roles played by individuals on the team. Table 2, taken from the TQM training provided to the Air Force Electronics Systems Division by Coopers & Lybrant and Change Navigators, is one example, describing four task oriented roles and four (team) process oriented. An individual may play different roles at different times.

TASK ORIENTED TEAM ROLES:

SHAPER - Keeps team focus on objectives

INNOVATOR - Source of ideas

ANALYZER - Evaluates ideas

IMPLEMENTER - Concerned with getting things done

PROCESS ORIENTED TEAM ROLES:

COORDINATOR - Concerned with achieving consensus

NETWORKER - Connects team to outside world

HARMONIZER - Concerned with feelings

GATEKEEPER - Concerned with keeping team standards

Table 2

Each of these roles has a place in helping the team work. Without a shaper, the team may drift. The innovator, who provides ideas, is complemented by the analyzer, who evaluates them. And so forth, down to the gatekeeper, who notices when the team is violating its established standards of conduct and brings it to the other members' attention. One Rome Laboratory team dramatically improved its performance after they realized that they lacked a shaper and recruited one.

Team Decision Process

Teams should strive to reach decisions by consensus. Consensus is reached when all the team members feel that the decision is the best possible under the circumstances and acceptable for their special interests. A decision reached by consensus will be supported by all concerned, while other ways of reaching decision will have lesser "buy-in" as shown in table 3 .

<u>DECISION PROCESS</u>	<u>"BUY-IN"</u>
NO DECISION	NONE
POWERFUL MINORITY RULES	SMALL MINORITY
TRADE-OFFS BETWEEN SPECIAL INTERESTS	MINORITY
MAJORITY RULE	MAJORITY
MAJORITY RULE - MINORITY OPINION EXPLORED	MAJORITY
CONSENSUS	ALL

Table 3

TEAM PROCESS EVALUATION TOOLS

A team should periodically evaluate its own process. There are a variety of helpful tools for this. Using the information in the previous section, a team can evaluate its position on the team wheel, assess the roles played by the team members (are all necessary roles present?), and discuss the degree of participation in the decision making process. They can also rate the team climate with a variety of surveys. Generally, these use a scale rating each member's agreement with such statements as:

- We are addressing the proper issues
- We are able to openly express ideas
- We feel comfortable giving feedback
- We spend our time well
- We often stray from the issue
- Everyone is participating
- We are following our code of conduct well
- Our goals are clear
- We have a high level of energy
- We usually achieve consensus
- etc.

The insight provided by the discussion of the survey results will help keep the team operating effectively. Surveys are available in text books and consultant's manuals. With a little thought, the user can probably create an effective survey on his own.

Facilitators

An objective view of a teams effectiveness, and useful feedback, can be obtained by using a facilitator. A facilitator is someone trained in group dynamics and team tools who monitors the team progress. He should not do any work on the team task, but rather devote all his attention to the team process. He may teach the use of evaluation and process tools. He will advise the team on-line and the team leader off-line. One facilitator may support many teams and need not attend every team meeting. The facilitator has his own tools. One is the interaction chart shown in figure 27.

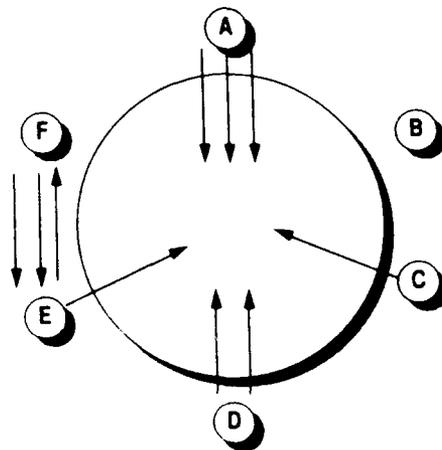


Figure 27

Figure 27 shows the communication during a segment of the team meeting. Each line represents an input from one of the team members. These can be coded by length or width to represent the relative length of the talk. The arrowhead on the line shows who received the input, with statements directed to the whole group pointed at the center. Figure 27 shows that the person labelled A dominated the discussion, person B did not participate and E and F held a separate meeting.

The facilitator can also make use of checklists to organize his observations. There are many of these, often with a particular focus. Examples are shown in table 4.

<u>FOCUS</u>	<u>SAMPLE ITEMS</u>
BEHAVIOR	Who: is friendly, holds back, shows tension, wants data, etc.?
BODY LANGUAGE	Who: avoids eye contact, frowns, leans back, stands up, etc.?
LEADERSHIP	Style of leader, effectiveness, decision process, etc.
ROLES	Are all necessary roles present?
GENERAL	What helped/hindered team? Does anyone dominate? Could the team hold a focus? Was it O.K. to disagree? etc.

Table 4

A facilitator can use available lists or make his own based on what observations could be most useful to the team.

TEAM PROCESS TOOLS

The team tools discussed above are designed to help the team work effectively, by evaluating their team process. Another set of tools is designed to aid their efficiency in going through the process to reach their objective. These include:

- Brainstorming
- Interviewing
- Affinity exercise
- Multi-voting
- Nominal group technique
- Pairwise ranking
- Mental imaging

BRAINSTORMING is used to generate ideas. The team leader starts the session by writing the topic where everyone can see it. He then explains that the goal for the exercise will be to generate as many ideas as possible and no idea will be analyzed or evaluated at this time. He may then proceed to a structured or unstructured approach. In the former, he will go around the table and each member will contribute one idea or pass, repeating the process until all pass. In the unstructured approach, team members contribute ideas as they come to them until all run out. Either way, the

ideas are written down as they come. A brainstorming session typically runs about 15 minutes; the results are often amazing. Once the ideas are captured, they can be discussed, organized, and evaluated.

INTERVIEWING is the way the team obtains inputs from stakeholders in the project who are not on the team. The process starts with the identification of the stakeholders, and the team should strive to include all possible viewpoints. A list of questions should then be prepared (or a set of lists, if appropriate), and appointments made with the people to be interviewed. Two interviewers are recommended; one does the talking and the other takes notes. The stakeholder should do most of the talking and should be encouraged to fully express his views. The team members should never argue or judge the input during the interview. The stakeholder should be thanked for his input, and the team must scrupulously perform any follow up activity promised to the stakeholder. It is usually appropriate to give the stakeholder some feedback of results, such as a copy of the team's final report.

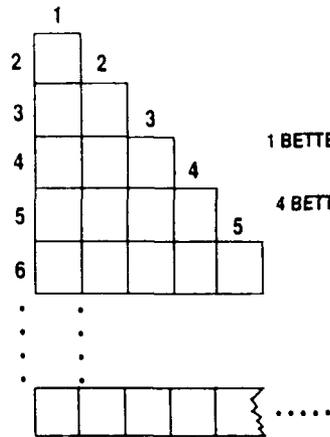
THE AFFINITY EXERCISE is another idea generator. It starts with a silent brainstorming session. For 15 minutes, the participants write their ideas on post-it notes, one idea per note, without any discussion. All notes are then posted on a wall, and for 20 minutes the participants read the notes and group similar ideas by putting the notes together. This also is done without discussion. Then a discussion is held to develop a theme for each group of notes. The theme will be a noun-verb combination such as "reduce paperwork." The themes are then grouped into action plans for making improvements. The silent brainstorming is used as it produces far more ideas than the usual procedures, despite the fact that people cannot build on each others ideas.

MULTI VOTING is a way to reduce a list of ideas or recommendations to those most important. Each member of the team is given a number of votes equal to about half the number of items on the list. Everyone votes for the items they consider most important. The four to six items getting the most votes get the priority. If votes are too close to isolate the top items, the items receiving few votes can be eliminated and a new multi vote taken on the remainder.

THE NOMINAL GROUP TECHNIQUE is another way to prioritize a list. After similar ideas have been combined, each item on the list is ranked by each team member. Item 1 is the least important, item 2 the next least important, etc. The individual scores from each team member are then added together, and the item with the highest score is the most important.

PAIRWISE RANKING assigns priorities by comparing the items on a list to each other one by one. A matrix is used, as shown in figure 28. The team is asked to compare list item 1 against 2, and the number of the preferred item is recorded in the top box of the matrix. The next row shows the winners of comparisons between items 1 and 3 and between items 2 and 3. After all items have been compared, the number of times each item number has been recorded in the matrix is calculated. The item whose number is recorded most is the most important. Should two items tie, the winner of the comparison between the two takes precedence.

1. NUMBER ITEMS
CONSTRUCT MATRIX



2. COMPARE ITEMS BY PAIRS,
COMPARE RESULTS

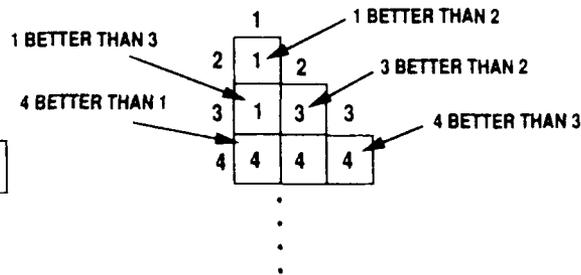


Figure 28

MENTAL IMAGING is an aid to planning. Each team member relaxes and imagines what the world would be like if the best possible outcome to their project were implemented. Their ideas are recorded and combined into a group vision. Then the current situation is assessed, and the gaps between the vision and current reality defined. The obstacles to closing the gaps are then identified and become the targets for the improvement plan.

GETTING STARTED

It takes some effort before a group of individuals becomes an effective team. Some never make it. Successful teams often have some help getting started in the form of specialized training. I recommend an orientation in group dynamics to include the team wheel, team roles, decision processes, and team evaluation tools. (The team process tools can be provided also or deferred until they are needed. The same applies to training in the analytical tools.)

The first team meeting should produce a charter and a code of conduct. The charter may be the objectives given the team by its sponsor, if specific enough. If not, the team should refine it to a clear objective that everyone understands and agrees to. For example: "Find ways to reduce the time required to obtain laboratory supplies." (Refinements should be subsequently verified by the sponsor.) The code of conduct is a set of rules the team intends to abide by in their activities. It might include:

- Be on time for scheduled meetings
- All opinions respected
- All statements held private
- No smoking
- 10 minute break every hour
- No hidden agendas
- etc.

With the charter and code of conduct, the team is starting in an organized fashion. The help of a trained facilitator is probably the most valuable in start up, to head off any bad habits. Some good habits to start with are the recording of minutes, the making and following of agendas, and the evaluation of task progress and team process at the end of each meeting. A simple evaluation should usually suffice (Is progress good or not, and where are we on the team wheel?) with more involved evaluation used when the simple answers are not good (getting nowhere and still in conflict).

ACTION PLANS

Action plans are ways of organizing quality improvement efforts. The most well known are the Shewhart cycle and the Quality Improvement Story. The Air Force Electronic Systems Division uses one called "Chart It - Check It - Change It" (C-cubed-I) which tracks, nomenclature-wise, with its mission to provide Command, Control, Communications and Intelligence (C-cubed-I) systems. Boeing uses a procedure simply called a seven step model for process improvement.

THE SHEWHART CYCLE is shown in figure 29. It is named after Walter Shewhart, a pioneer in statistical quality control and a mentor of Dr. Deming. It is also known as the Deming cycle because of its advocacy by Deming. It starts with planning, which could be the planning of an experiment, the identification of data needed to analyze a process, or the planning of any activity for quality improvement. The next step, the "Do" cycle, is to follow through on the plan. The results of the Do phase activity are analyzed in the "Check" phase. The last phase, "Act," is to follow up on the conclusions from the analyze phase. From the Act phase, one returns to the planning phase for the next improvement project. Each trip around should result in a better situation for the cycler.

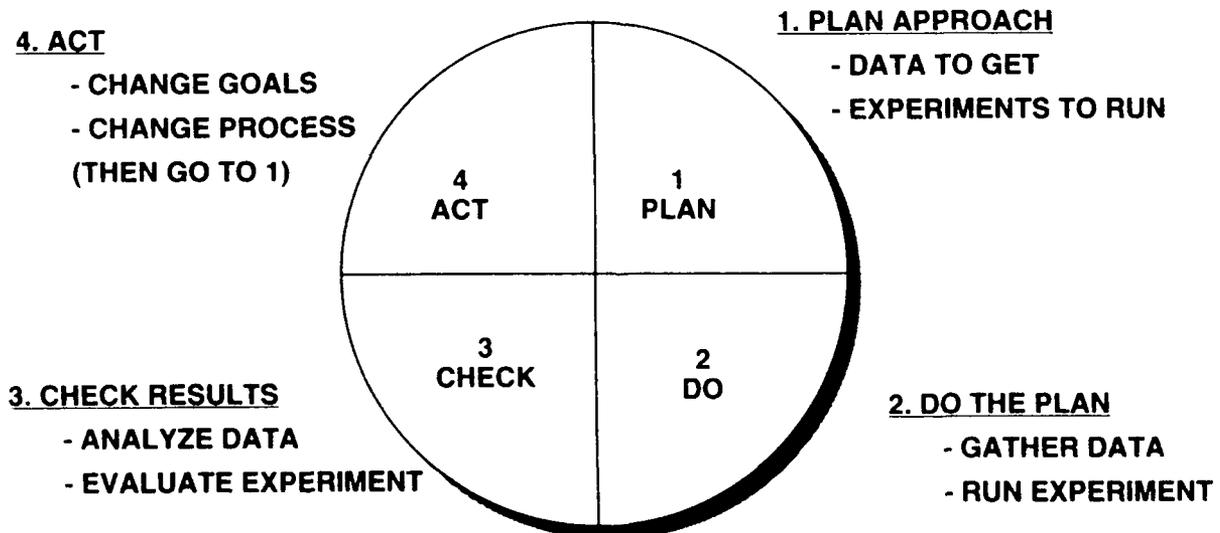


Figure 29

The QUALITY IMPROVEMENT (QI) STORY is a sequential procedure for action. There are various versions. One of these is:

QI STORY

1. THEME - What is the problem/opportunity?
2. SCHEDULE - The plan to finish the story.
3. CURRENT CONDITION - What are the facts? (collect data not anecdotes.)
4. CAUSE-EFFECT ANALYSIS - Determine & prioritize causes of current condition.
5. CAUSE VERIFICATION - Collect data to prove cause "guilty."
6. COUNTERMEASURES - What can be done to remove cause?
7. COUNTERMEASURE EFFECTIVENESS - Does it work? (data)
8. TOTAL EVALUATION - Will countermeasures mess up something else?
9. STANDARDIZATION - Make the improvement permanent.
10. FUTURE ACTIONS - What's next? (go to 1)

The outline for CHART IT - CHECK IT- CHANGE IT (C-CUBED-I) is:

1. CHART IT:
 - Identify process, put into flow chart
 - Gather data on process
2. CHECK IT:
 - Analyze data, isolate problems/opportunities in process
 - Identify alternate approaches
 - Select opportunities for improvement (useful alternatives)
3. CHANGE IT:
 - Change process to implement improvement
 - Standardize change

The BOEING SEVEN STEP MODEL FOR PROCESS IMPROVEMENT is:

1. ASSIGN PROCESS OWNER AND DEFINE BOUNDARIES
2. FLOW CHART PROCESS
3. ESTABLISH EFFECTIVENESS AND EFFICIENCY MEASURES
4. DETERMINE PROCESS STABILITY
5. IMPLEMENT PROCESS IMPROVEMENTS
6. VALIDATE IMPROVEMENT
7. DOCUMENT IMPROVEMENT

ASSESSING QUALITY EFFORTS

The Malcolm Baldrige National Quality Award

The Malcolm Baldrige National Quality Award was established in 1987 to stimulate American companies to improve quality, recognize achievements, establish guidelines for self-evaluation, and make available information from successful organizations. Winners in 1988 were Globe Metallurgical, Motorola, and a nuclear fuel division of Westinghouse. In 1989, Milliken and Xerox Business Products took the awards. In 1990 it was Cadillac, IBM Rochester, Federal Express, and the Wallace Company. The award is not without detractors, who argue that the Baldrige criteria may not be the only way to world class quality. They note, for example, that the emphasis on participatory management assumes that other management approaches would not work. Nevertheless, the Baldrige criteria is a de facto standard for judging the quality efforts of an organization and the basis for most other criteria such as a growing number of regional quality awards. The 1991 Baldrige criteria and the relative weights given to each factor are shown in table 5:

<u>FACTOR</u>	<u>WEIGHT</u>
1.0 LEADERSHIP	100 POINTS
2.0 INFORMATION AND ANALYSIS	70
3.0 STRATEGIC QUALITY PLANNING	60
4.0 HUMAN RESOURCE UTILIZATION	150
5.0 QUALITY ASSURANCE OF PRODUCTS AND SERVICES	140
6.0 QUALITY RESULTS	180
7.0 CUSTOMER SATISFACTION	300
	<u>1000</u>

Table 5

LEADERSHIP is further divided into the subfactors of Senior Executive Leadership (40 points), Quality Values (15), Management for Quality (25) and Public Responsibility (20). INFORMATION AND ANALYSIS includes Scope and Analysis of Quality Data and Information (20), Competitive Comparisons and Benchmarks (30), and Analysis of Quality Data (20). STRATEGIC QUALITY PLANNING includes Strategic Quality Planning Process (35) and Quality Goal and Plans (25). Subfactors of HUMAN RESOURCE UTILIZATION are Human Resource Management (20), Employee Involvement (40), Quality Education and Training (40), Employee Recognition and Performance Measurement (25), and Employee Well-Being and Morale (25). QUALITY ASSURANCE includes Design and Introduction of Quality Products and Services (35) Process Quality Control (20), Continuous Improvement of Processes (20), Quality Assessment (15), Documentation (10), Business Process and Support Service Quality (20), and Supplier Quality (20). QUALITY RESULTS is divided into Product and Services Quality Results (90), Business Process, Operational, and Support Service Quality Results (50), and Supplier Quality Results (40). Finally, CUSTOMER SATISFACTION includes Determining Customer Requirements and Expectations (30), Customer Relationship Management (50), Customer Service Standards (20), Commitment to Customers (15), Complaint Resolution for Quality Improvement (25), Determining Customer Satisfaction (20), Customer Satisfaction Results (70) and Customer Satisfaction Comparison (70).

Each of these subfactors is further divided into two to four areas to address. As a result, Baldrige applications take significant effort. However, the process gives the preparer a deep insight into his organization's quality efforts. Without any intent to apply for the award, an organization can take advantage of the criteria for a self-assessment. A copy of the Applications Guidelines can be obtained, free, from:

Malcolm Baldrige National Quality Award
National Institute of Standards and Technology
Route 270 & Quince Orchard Road
Administration BLDG, Room A537
Gaithersberg MD 20899
(Telephone 301-975-2036)

The Quality Improvement Prototype (QIP) Award

The Quality Improvement Prototype (QIP) Award was established to:

1. Recognize (Federal) organizations that have successfully adopted TQM principles and thereby improved the efficiency, quality and timeliness of their services or products.
2. To use the QIPs as models for the rest of government, showing other agencies how a commitment to quality leads to better services and products.

The QIP evaluation criteria and weights are shown in table 6:

QUALITY ENVIRONMENT	20 POINTS
QUALITY MEASUREMENT	15
QUALITY IMPROVEMENT PLANNING	15
EMPLOYEE INVOLVEMENT	15
EMPLOYEE TRAINING AND RECOGNITION	15
QUALITY ASSURANCE	30
CUSTOMER FOCUS	40
RESULTS OF QUALITY IMPROVEMENT EFFORTS	50
	<u>200</u>

Table 6

QIP applications are available from:

Quality Improvement Prototype Award
c/o Quality Management Branch, Room 6235
Office of Management and Budget
725 17th street, N.W.
Washington DC 20503

Quality and Productivity Self-assessment Guide
for Defense organizations

Designed specifically for self-assessment, the Quality and Productivity Self-Assessment Guide for Defense Organizations contains rating scales for

Climate (peoples perceptions about the organization), Processes (tne organizations policies and practices), Tools (specific techniques used to promote quality) and Outcomes (results). The climate questions can be given separately with the idea that a broad survey of climate and a smaller sample of the other factors would be effective. A scoring guide includes suggestions to help raise low ratings. The guide is available in an automated format for use with a personal computer.

Copies may be requested from:

John Denslow
OASD/DPP0
Two Skyline Place, Room 1404
5203 Leesburg Turnpike
Falls Church VA 22041-3466
(Telephone 703-756-2346)

MEASURING THE QUALITY OF KNOWLEDGE WORK

Measuring quality is most difficult for the managers of knowledge workers. One reason is that there is no universally accepted standard definition for quality. Indeed, David A. Garvin identified five categories of definitions for quality. These are:

1. Transcendent quality: a subjective feeling of "goodness".
2. Product-based quality: measured by attributes of the product
3. Manufacturing-based quality: conformance to the specifications
4. Value-based quality: "goodness" for the price
5. User-based quality: the capacity to satisfy the customer

One should note that the categories are not mutually exclusive. In particular, no matter which definition is used, quality is always ultimately defined by the customer (i.e. user-based). Let's look at these categories and see how they apply to knowledge work.

Transcendent Quality Measures

Transcendent quality measures are merely means for capturing subjective opinions. The most common tool used is the rating scale. For example, cake mixes are tested by submitting their products to a panel which rates the taste of the cake on a scale from one to five, with five being the best possible. Knowledge workers sometimes use peer ratings in a similar manner. When an attribute is actually subjective, like taste, the transcendent cannot be challenged. In areas where other measures are possible, the more objective measures are generally preferable. Even so, the transcendent opinion of the customer is the most important measure of one's quality.

In the author's opinion, a useful area for transcendent measures of quality is in the appraisal of individual performance. Dr. Deming condemns

the use of annual appraisals for several reasons. However, appraisal systems will probably be with us for a while, and the use of transcendent measures may be one way to make them work. My recommendation is to use general categories (e.g. shows initiative) scored by the subjective opinion of the employee's supervisor, on the assumption that the supervisor's transcendent quality judgement of the employee is likely to be an accurate measure (He will know quality work when he sees it).

Even when using more objective quality definitions, the transcendent can be useful as a "sanity check". If a measured quality value "feels" too high or too low, perhaps your intuition is calling for you to reevaluate your selection of measures.

Product-based Quality Measures

Product-based quality is measured by the amount of some desired ingredient or attribute. For example, the speed of a computer. In knowledge work, one desired attribute may be innovation. The difference is, of course, that it is much easier to measure speed.

Since innovation and other intangible features are desired not for themselves, but for their impact on the product, measurable units such as speed will reflect the quality of knowledge work once the work is transitioned into hardware or software. Under such circumstances, system parameters can be measured to establish the quality of the underlying knowledge work. One would select the only most meaningful measures. To be effective as quality measures, however, the measured values must be referenced to some benchmarks. For example, the speed of a computer is useless for quality evaluation unless the analyst knows what other machines deliver.

A problem with attribute measures is that trade-offs may not be recognized. Speed may be enhanced at the expense of payload which may or may not be an improvement overall. One way to evaluate this is the use of all-encompassing measures such as "systems effectiveness," defined as a function of a system's availability, dependability and capability against a specified threat. In the simplest case, availability is the probability of a system being operable when needed, dependability the probability that it will remain operable for the length of a mission and capability the conditional probability that, if operating, it will successfully complete the mission. For this simple case:

$$\text{System Effectiveness} = (\text{Availability}) \times (\text{Dependability}) \times (\text{Capability})$$

An approach between the measurement of a few selected parameters and the calculation of system effectiveness is the use of indexes. Indexes are artificial, but supposedly not arbitrary, groupings of measures into an overall single measure. Examples are the consumer price index and the index of leading economic indicators. Similarly, a quality index can be created by identifying parameters of interest, establishing measures, weighing the measures and combining them into one. As a simple example, Robert Gunning invented a "fog index" for evaluating understandability of text, calculated by computing the average sentence length, adding this to the number of words of three syllables or more in 100 words, then multiplying by 0.4. Though

Gunning claims his index corresponds roughly with the number of years of schooling a person would require to read the text with reasonable ease, an index figure is generally not meaningful in absolute terms, but, rather, useful for showing trends.

The more tangible the product, the better product-based measures work. However, in knowledge work the product is often intangible, such as a set of recommendations, so product parameters cannot be measured. One alternative is to use even more indirect measures so long as they also correlate with the attributes desired. For example, a large number of patents held should indicate an innovative agency. Some other measures might be the ratio of in-house to contracted work, numbers of papers published, resources spent on education and training activities, advanced degrees earned, name requests for consulting committees received, and the amount of national/international professional activity among the knowledge workers. These are measures of the laboratory climate or environment favoring quality knowledge work.

One could also measure the climate opposing quality in knowledge work. Common measures indirectly showing unfavorable climates include absenteeism, turnover percentage, average sick days taken per employee, etc. Poor environments could perhaps be more directly measured by the number of approvals required to do work, the ratio of overhead to productive activity, the length of time required to obtain a part or a piece of test equipment, etc. These could be labelled "Hassle Indexes."

Manufacturing-based Quality Measures

Perhaps the best illustration of manufacturing-based quality definitions was proposed by Philip Crosby, who equated quality to compliance with specifications. This, of course presumes tangible products or services, which for knowledge work could include such items as technical reports and briefings as well as the more obvious hardware and software end products.

The most commonly used manufacturing-based quality measure is defect rate (i.e. the percent of the product not in compliance to specifications). Defect rate is a universal quality measure and can be applied to knowledge work as well as manufacturing by formulating an appropriate operating definition of defect. Cycle time is another widely used manufacturing-based measure which is easily applied to knowledge work.

Another manufacturing-based quality measure is the variation among products. All products will have some variation, and the greater this is, the more defects there will be. Variance can be measured in various ways, such as by range or by standard deviation (sigma). The lower the value of sigma, the more uniformity in the product. Variance, however, is not the whole story. Both the mean and variance are important. A measure which considers both is called process capability (Cp). It compares the mean and variance of a product parameter to specified limits.

$$Cp = \frac{\text{upper specification limit} - \text{lower specification limit}}{6 \text{ sigma}}$$

With a normal distribution, a Cp of 1.0 means that 99.7% of the product would be "in spec" assuming the mean of the product is centered between the upper and lower control limits. To allow for means in other locations, a Process Performance (Cpk) Index can be used.

$$Cpk = \frac{\text{(minimum distance between the mean and either control limit)}}{3 \text{ sigma}}$$

Using either measure, the higher the value, the better. Motorola's "six sigma" program strives for a Cp of 2.0 (six sigmas between the target mean and the specification limits) which, when the true mean is 1.5 sigmas off target, translates to a defect rate of 3.4 parts per million.

For non-structured work, the main issue with manufacturing-based quality definitions is determining what the "specification" is. A specification for a study on Computer Technology may specify the format, perhaps even the type style, of the final report, which are all of secondary importance to a host of considerations such as responsiveness, innovation, realism, clarity, etc. With the exception of the fog index for understandability, I have found no specifiable measures of these critical desires. If one assumes that meeting the specifications for a product reflects desired intangibles like innovation, measuring conformance is adequate. Otherwise, the manufacturing-based measures simply will not work. One could specify that a product show innovation, but verification of compliance would require a subjective opinion, which is a transcendent, not a manufacturing-based quality measure.

Manufacturing-based quality figures do have an important place in knowledge work. A laboratory's operations include many processes and sub-processes. It is important to note that in knowledge work, as in any other, the final customer is only the last of a series. Each office involved in a process is the customer for some input and the provider of some output to another customer. Thus, even the process of creating innovations will include such processes as publishing reports, obtaining laboratory equipment, awarding contracts, etc., which can be evaluated by manufacturing-based quality measures. Improving these processes must improve the laboratory operations, even if we totally ignore intangibles such as innovation. For example, shortening the time to obtain a needed instrument yields more time for performing experiments with it, which in turn can produce more innovations.

Process improvement is the heart of Total Quality Management (TQM). Improving the process can be accomplished by radical innovations or by accumulation of many small changes. Either way, it begins with an understanding of the process, and depends on the measurement of quality indicators. The process itself should tell you what to measure. If the process is proposal evaluation, for example, cycle times and/or the number of corrections required (defects) may be compiled to establish a baseline against which proposed improvements can be compared.

One danger in measuring a process is that what you measure becomes the priority, and some ways of improving one parameter may deteriorate other critical parameters. Optimizing a process may therefore adversely impact a larger process in which it is imbedded, or the quality of the process by other measures. For example, improvements in the cycle time for proposal

evaluations can be made by taking less care in doing the work, for a loss in quality measured by the number of errors. As always, the test of value added is the overall impact on the customer.

Value-based Quality Measures

In value-based quality definitions, cost is a consideration. A low cost automobile which provides dependable and reasonably comfortable transportation would be considered a quality vehicle even if it does not have the features of a Rolls-Royce. In fact, the Rolls-Royce may be considered too expensive for what it provides and hence not good value for the average consumer. Quality is also not independent of schedule. As discussed above, cycle time is a measure of quality, but improving cycle time can adversely affect other facets of quality such as product defect rates. Conversely, a good product delivered too late may be of no use to the customer.

The author's view of value-based quality is that every product, service or process can be measured in three dimensions: cost, time, and some measure of "goodness," such as percent defects. Improvements which change one without detriment to the other two are always worthwhile. Other changes may or may not be worthwhile depending on the overall effect on the customer. While the trade-offs between cost, schedule and "goodness" can be a subjective matter, all quality decisions should try to balance the three considerations. For example, contracting can be measured by cycle time (schedule), overhead man-hours (cost) and number of protests per contract (defects). Measuring only one of these invites sacrificing the others. For ease of reference, let's call a balanced combination of cost, schedule and "goodness" measurements a "quality troika."

Another approach to using value-based measures is to distinguish between effectiveness and efficiency. Effectiveness measures the "goodness" of a product or service for its user, while efficiency considers the cost of making it happen. To illustrate the difference, consider the example of supplying integrated circuits meeting the customer's needs by making much more than ordered and screening the output. The customer may be pleased with the product (high effectiveness), but the cost of quality will be higher than it should be (low efficiency). Effectiveness can be measured perhaps by sales (or the laboratory equivalent: amount of external funding), market share, or one of the product-based measures. Efficiency is measured by the cost of quality, overhead rates, or one of the manufacturing-based measures.

The Cost of quality includes the cost of preventing defects, the cost of inspection, the cost of rework and the cost of waste. Many companies consider only the money spent by their quality professionals (in prevention and inspection) as the cost of quality. In reality, a typical company may be spending 25% of its manufacturing costs on rework and scrap. One way of measuring quality could therefore be the determination of all the measurable components of the cost of quality. The lower the cost of quality, the higher the efficiency of the quality effort.

Still another approach is the use of calculations based on the Taguchi loss functions. The computed loss can represent actual costs for repair of a defect, or immeasurable costs such as lost business or the "loss to society" because of poor quality.

User-based Quality Measures

As previously stated, all measures of quality must ultimately be user-based. The problem is translating user satisfaction to an appropriate quality measure. The most quoted user-based definition of quality is that of J. M. Juran, who defined quality as fitness for use. Juran divides fitness for use into two categories: features and freedom from deficiencies. Features, he stated, cost money and attract customers, while freedom from defects saves money and keeps customers. Knowledge work features could include innovations, responsiveness, ease of comprehension of ideas presented, etc. and freedom from defects includes accuracy, legibility of written reports, etc. Under this definition, product-based quality measures become user-based measures for evaluating features and manufacturing-based measures become user-based measures for evaluating freedom from defects. Transcendent and value-based quality measures may measure either features, freedom from defects, or overall fitness for use, depending on application.

From this discussion, there seems to be a plethora of ways to measure the quality of knowledge work. Table 7 summarizes these.

QUALITY MEASURES FOR KNOWLEDGE WORK

PURPOSE:	RATE CUSTOMER SATISFACTION	APPRAISE AGENCY	APPRAISE INDIVIDUALS	IMPROVE PRODUCTS AND PROCESSES
MEASURE:	Rating scales Product parameters Performance indexes Systems effectiveness Defect rates Cp or Cpk Cycle times	Rating scales Climate indicators Defect rates Cp or Cpk Cycle times Cost of quality Overhead rates Sales, Market share	Rating scales	Defect rates Cp or Cpk Cycle times Quality troikas Loss functions
TYPE OF MEASURE:	Transcendent, Product-based, or Manufacturing-based.	Transcendent, Product-based, Manufacturing-based, or Value-based.	Transcendent.	Manufacturing-based or Value-based.

Table 7

CONCLUSIONS

I hope the reader is convinced that TQM is worthwhile, and recognizes that it is not easy. Success in implementing TQM requires commitment, training, persistence, and understanding. Figure 30 summarizes the TQM process. As a final offering, the author would like to propose his own formulation of TQM principles, consisting of only six points. These principles should track well with other formulations mentioned in the TQM literature, except that I don't believe my sixth point is emphasized enough.

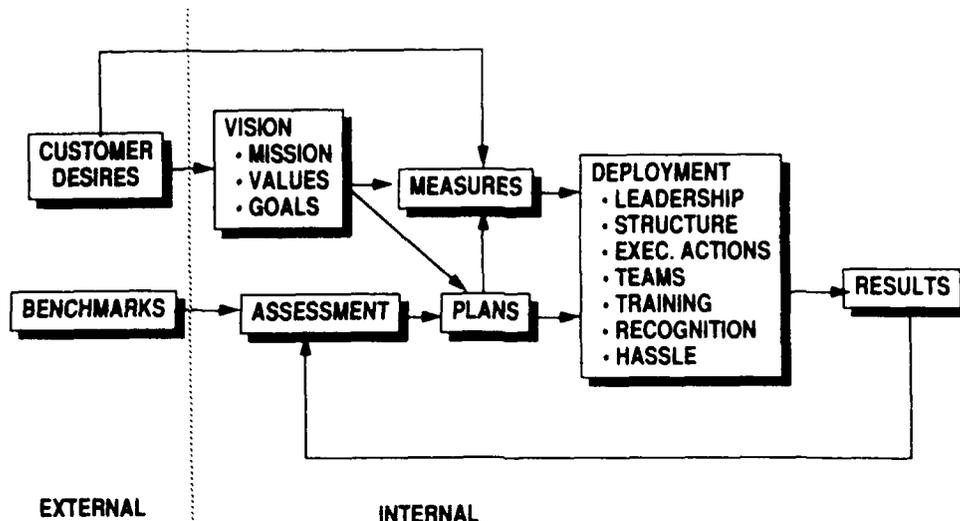


Figure 30

COPPOLA'S SIX POINTS

1. LEADERSHIP. MANAGEMENT MUST:
 - SHOW COMMITMENT
 - COACH THE PLAYERS
 - SUPPORT THE EFFORT
2. PROCESS IMPROVEMENT.
 - PREVENT DEFECTS
 - BUILD TEAMS
 - BREAK DOWN BARRIERS
3. EDUCATION AND TRAINING. - INSTEAD OF EXHORTATIONS
4. USE OF KNOWLEDGE AND DATA. - IF IT'S IMPORTANT, MEASURE IT
5. CUSTOMER SATISFACTION. - ALWAYS. BUILD THE BUSINESS TO DELIGHT THE CUSTOMERS, NOT THE MANAGEMENT.
6. REBELLION. - AGAINST ANYTHING THAT DOES NOT ADD VALUE.

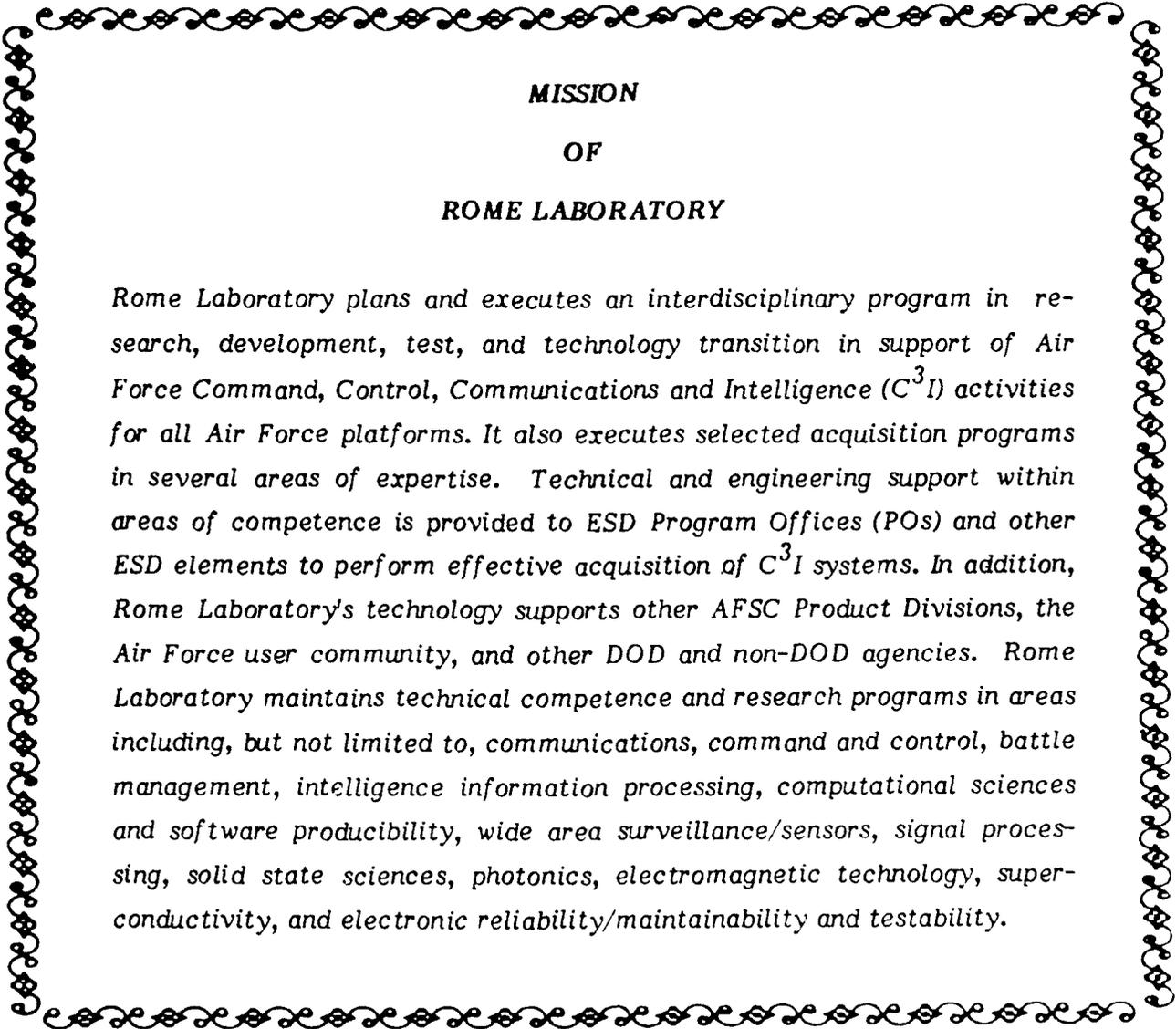
Let us end with this:

FINAL EXAM

TQM IS:

- A. A BUZZWORD
- B. A WAY OF LIFE
- C. A LIVING FOR CONSULTANTS

ANSWER: YOUR CHOICE



**MISSION
OF
ROME LABORATORY**

Rome Laboratory plans and executes an interdisciplinary program in research, development, test, and technology transition in support of Air Force Command, Control, Communications and Intelligence (C³I) activities for all Air Force platforms. It also executes selected acquisition programs in several areas of expertise. Technical and engineering support within areas of competence is provided to ESD Program Offices (POs) and other ESD elements to perform effective acquisition of C³I systems. In addition, Rome Laboratory's technology supports other AFSC Product Divisions, the Air Force user community, and other DOD and non-DOD agencies. Rome Laboratory maintains technical competence and research programs in areas including, but not limited to, communications, command and control, battle management, intelligence information processing, computational sciences and software producibility, wide area surveillance/sensors, signal processing, solid state sciences, photonics, electromagnetic technology, superconductivity, and electronic reliability/maintainability and testability.